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[Official history of the War]:

STORY OF THE GREAT WAR

BASED ON OFFICIAL DOCUMENTS

MEDICAL SERVICES.
SURGERY OF THE WAR

VOL. I

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Note.—(T) means temporary commission. (T.F.) means Territorial Force commission. (S.R.) means Special Reserve.

PREFACE.

THE unparalleled number of battle casualties which occurred during the war gave the consulting and specialist surgeons who were employed with the British medical units an unrivalled opportunity for surgical work, and as the years went on the improvements in method and the skill acquired in dealing with wounds placed war surgery in a position which it had never occupied in the past.

The account of this work, recorded in the two volumes of the Surgery of the War, has been prepared by the consulting surgeons and by some of the surgical specialists who held commissions in the Royal Army Medical Corps.

The present volume contains chapters on general subjects affecting the surgery of the war, and indicates the development of front-line surgery and wound treatment generally, followed by chapters on wounds of the thorax and abdomen. The second volume deals with wounds of the blood vessels, head, face and jaw, neck, spine and extremities, including orthopædics, and injuries of the eye and ear.

As by far the greatest proportion and variety of wounds occurred on the Western Front, the chapters have been prepared chiefly by officers who were serving with the armies in France, where there were also frequent and ample opportunities of observing the surgical work of the allied French and Belgian forces. A review, however, of special conditions affecting wounds in some other theatres of war is included.

In the year 1915 a " Memorandum on Injuries in War " was drawn up under the orders of the Director-General of the Medical Services in France by a committee of the consultants. A second and larger edition was issued under the title " Manual of the Diseases and Injuries of the War," at the end of 1917. These publications were intended to indicate the lessons learnt during the war and to maintain uniform methods of practice, especially in the front line units. Copies of both were given to all medical officers on joining the British Expeditionary Force in France, and copies of the latter edition were also sent to the directors of medical services in other theatres of war.

In addition to these means of distributing information, meetings of representative surgeons of the allied armies were

held in Paris every six months from May 1917 onwards, and the proceedings were published in three volumes under the title of *Rapports des Conférences des Chirurgiens Consultants interalliés.*

In this way the advances made on the whole Western Front in the surgery of the war were brought to the notice of the medical services of all the allied armies.

So far as treatment of injuries is concerned, it has not been found either possible or advisable to follow step by step every change that occurred during the war. The object has rather been to describe only those methods which at the end of the war had been found to be the most trustworthy.

It has also been impossible to ascertain accurately the relative incidence of wounds of the different parts of the body, but, for the years 1914 and 1915, the statistics obtainable from the admission and discharge books of the medical units give the results shown in Appendix A. Although they cannot be regarded as going very far from the surgical point of view, because they do not indicate the exact anatomical region of the injury, or injuries that were multiple in nature, they are of some value as a guide to administrative medical officers in estimating the amount and nature of ambulance transport, surgical dressings, and apparatus required in preparations for planned battles, such as those of the year 1915, or during encounter battles as in 1914.

Sir Anthony Bowlby, Sir Cuthbert Wallace, and Sir Crisp English have been responsible for the chief work of editing the volumes.

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W. G. M.

CHAPTER I.

PROJECTILES.

INTERNATIONAL AGREEMENTS. ENEMY PROJECTILES. MODE OF ACTION OF PROJECTILES.

IN an account of the wounds of any particular campaign with special reference to the missiles causing them, it is necessary to consider first the nature of the missiles used; secondly, their mode of action, that is, the intentions of their designers as to the effects they should produce and their actual behaviour in flight; and thirdly, their experimental effects upon animal tissues, and the observed results of their action in the field and in the various areas covered by the medical department from front to base.

Under these headings then the subject of projectiles will be considered, but before dealing with them there is a point of interest which naturally arises. In every campaign of late it has been usual to find accusations by one or other belligerent that the enemy was employing "unlawful" missiles. In view of this fact and because the war was no exception to the rule, it may be worth while to note the agreements which limited the use of certain kinds of instruments of violence in European warfare.

Four important international documents provide a fairly complete code for the guidance of combatants in land warfare —the unratified Declaration of Brussels of 1874, the Second Convention of the Peace Conference of 1899, the Fourth Convention of the Peace Conference of 1907, and the Geneva Convention of 1906. The United States had led the way by drawing up a series of rules in 1863, which were adopted, except in so far as they dealt with the question of *levées en masse*, by Germany in 1870; and the Conference of the Powers at Brussels in 1874 drew up a Declaration in that year, which was, however, never ratified, Great Britain and Germany in particular declining to accept it at the time, though it subsequently became the basis of the Conventions agreed upon at the Hague. But even in 1899 and 1907 there was no unanimity, chiefly owing to the difficulties arising on the question of the conditions under which combatants may be recognized and treated as belligerents, and the result was

that the actual Regulations were set out as annexes to the Conventions, the contracting parties only agreeing to issue instructions to their forces in conformity with these Regulations without expressly binding themselves to accept them in their entirety. They are "general rules of conduct for belligerents in their relations with each other and with populations," though it is to be noted that a certain binding force is recognized in them by the provision of the Convention of 1907, which supersedes that of 1899, that belligerent parties violating the Regulations shall make compensation "if the case demands." In the preambles to both Conventions (1899 and 1907) it was laid down that "it could not be intended by the high contracting parties that the cases not provided for should, for want of a written provision, be left to the arbitrary judgment of military commanders. Until a more complete code of the laws of war can be issued, the high contracting parties think it expedient to declare that in cases not included in the Regulations adopted by them, populations and belligerents remain under the protection and the rule of the principles of the law of nations, as they result from the usages established between civilized nations, from the laws of humanity and the requirements of the public conscience."

Not every mode nor instrument of violence is permitted by the laws of war. The general principle must always be observed that only such violence is permissible as is reasonably proportionate to the object to be obtained, namely, the breaking down of the armed resistance of the enemy. The preamble of the Declaration of St. Petersburg in 1868 recognized that "the only legitimate end which States should aim at in war is the weakening of the military forces of the enemy, and to this end it is sufficient to put out of action the largest possible number of men, and that this end would be exceeded by the use of arms which would uselessly aggravate the sufferings of men put out of action, or would render their death inevitable." The rules on this point, as at present agreed in principle, are set out in Articles 22 to 28 of the Annexe to Convention IV. of 1907, which expanded and amended the provisions of the Declaration of Brussels, and of the Convention of 1899, ratified on behalf of Great Britain in November 1909. After laying down that the choice of means of injuring the enemy is not unlimited, the rules particularly forbid the use of poison or poisoned weapons, and the use of arms, projectiles or substances likely to cause unnecessary suffering.

The permissibility of the use of the Dum Dum bullet, Mark IV pattern, which has a small cylindrical cavity in the head over which the hard metal envelope is turned down, was much discussed at the Hague in 1899. Explosive bullets have been discontinued since the Declaration of St. Petersburg, 1868, but the representatives of Great Britain in 1899 refused to concur in an agreement which would have required all bullets to be cased in hard envelopes. The Conference drew up a Declaration in favour of abstension from the use of bullets "which expand or flatten easily in the human body, such as bullets with hard envelope which does not entirely cover the case or is pierced with incisions." But Lord Lansdowne instructed Sir Julian Pauncefote to inform the Conference that the Chitral campaign of 1895 had demonstrated the insufficiency of a hard envelope for stopping a rush in savage warfare. On this ground, and contending that the Dum Dum bullet did not inflict unnecessary suffering, the British Government, and with it the United States, refused to sign this Declaration; but the objection was, so far as Great Britain was concerned, based only on the argument from savage warfare, as the bullet was not used by the British in the South African War, and its use occasionally by their adversaries formed the subject of strong protests. However, in 1907, Great Britain and Portugal intimated their accession to the Declaration, and of the larger Powers only the United States has not yet assented to it, though willing to agree to the prohibition of bullets inflicting unnecessarily cruel wounds or exceeding the limit necessary for placing a man *hors de combat*.

The above is a summary of what has been attempted by civilized Europe to mitigate the severities of warfare. It will be seen that these agreements fall into two parts. There is on the one hand an acceptance of the fact that all and any methods of destroying life are not permissible to civilized peoples, and on the other an attempt to eliminate the unlawful methods by name. These latter are set forth in Annexes to the Convention, but the assent which is given to them can only be described as unwilling. The Powers will "issue instructions in conformity with the regulations," but they will not expressly bind themselves "to accept them in their entirety," a reservation which goes far to sterilize the agreements. Germany, by word and deed and with outspoken frankness, declared its reliance upon absolutely ruthless warfare, and it may be inferred that in any case the Regulations

would be interpreted according to such factors as racial characteristics, political pressure, standards of civilization, national sense of danger or assurance of immunity from punishment. This is no more than might have been expected. And in fact one by one in the course of the war the Regulations were broken until not one was left.

Again, on a retrospective view of the fighting in the war it must be seen that hampering restrictions as to the use of poison gases, explosive bullets, bombs from aircraft, and expanding bullets, even if they had been respected, would by no means have prevented all the " unnecessary suffering."

Humanitarianism, in fact, in nations wealthy and industrially efficient cannot keep pace with the inventiveness of destructive science. It was not even foreseen that an alteration of or an improvement in the tactical use of even such weapons as were allowed might be responsible for a vast increase of suffering. The Hague diplomatists excluded the explosive bullet but were not in a position to know the severity of wounds caused by concentrated machine gun fire, or by a barrage of six inch shells charged with high explosive. And yet nothing is more certain than that multiple wounds due to machine gun fire are among the severest injuries recorded in military surgery. Moreover, when statistics of the present war are completed it will certainly be found that shell and shrapnel wounds are in a very much higher proportion to bullet wounds than in any previous war. And of the two there can be little doubt that the shell wound, if it lacks in many cases the penetrative severity of the bullet wound, is as often immediately fatal and carries a fourfold danger of infection and septic after-effects. No international agreement, however, limits the artillery barrage or the use of as large a field gun as road or rail will carry.

But even if some measure of international police had been found effective to compel the observance of agreements, it is questionable if the Powers took the best means of informing themselves as to the terms in which agreements should be drawn up. To find means of " weakening the military forces of the enemy, which would not uselessly aggravate the sufferings of men put out of action, nor render their death inevitable " obviously demands the co-operation of those who are specially engaged in dealing with wounds inflicted by the missiles of war, and of these individuals the military surgeon and the big game hunter are the most conspicuously expert. Clean healing is as much the object of the one as clean killing

is the object of the other, but on the question of unnecessary suffering the military surgeon stands alone. And on the subject of wounding by artillery projectiles, bombs, and the like, he is clearly an authority.

There is a large body of surgical literature dealing with wounds in warfare and covering the period of the most recent campaigns, waged with the most modern weapons. Military surgeons have experimented with modern rifles and ammunition with a view to informing their professional brethren as to the kind of injuries they may have to deal with in warfare. But it does not seem that this work was even noticed by the diplomatists at the Hague, or that it has had very much influence upon military practice. Thus the publication of Fessler's work in 1905 upon the effects of the pointed bullet, the typical small arms missile in the war, did not prejudice its adoption by practically all the great Powers, though the more humane type of wound caused by the blunt-nosed small bore cylindrical bullet was well shown in the records of the South African War.

The evidence of the big game hunter is of secondary importance from a humanitarian point of view, but as far as the killing effectiveness of any particular make of rifle goes it is of great value. Indeed, from the standpoint of the designer of small arms the big game hunter's word is the decisive one, so that it is not wonderful that the military rifle tends to approach the clean killing rather than the clean healing ideal. The dilemma raised by these almost irreconcilable ideals has led to one curious situation. When the blunt-tipped small bore bullet was introduced it was found to lack " stopping power " against determined enemies or charging wild beasts. Experience with the pointed bullet, however, showed that the difficulty had been overcome. But in the interregnum a bullet of the forbidden type was used against savage foes, by which it will be seen that the trend of military opinion was towards the big game hunter's results and away from the more humane type of bullet.

The Germans introduced the pointed bullet into military use ; they experimented with it and were fully informed of its superior powers of injury, and characteristically enough they were the first to complain of it. In December 1914, Professor Kershner of Königsberg suggested that by removing the tip the British bullet could be converted into a Dum Dum bullet, and some of his colleagues stated their belief that the British bullet was intended to be used as an expanding one, and

alleged that a device for removing the tip was provided on the rifle. Professor Stargardt of Hamburg went somewhat further and complained that the composite character of the British bullet was such that it broke up easily in the tissues and so approximated in its effects to an explosive bullet. While there is no need to assert our innocence of both these charges, they are a testimony to the enhanced severity of the wounds by pointed bullets, a fact which even some German observers realized. At a meeting of German army surgeons at Lille in January 1915, Dr. Braun stated that wounds by the British bullet differed in no essential point from those inflicted by ordinary rifle bullets. He had attempted to convert the ordinary bullet into a Dum Dum by the methods supposed to have been adopted by British soldiers in the trenches, but had found that such "doctoring" interfered with the automatic loading of the rifle and with the range and penetrative power of the bullet. He found that the "Dum Dum bullets of the English are mainly the products of fantasy." These comments appeared early in the war, and subsequently, as will be seen below in dealing with enemy ammunition, the enemy used both "doctored" and actual explosive bullets.

To sum up then, one is forced to the reluctant conclusion that in the absence of power to enforce them, international agreements are of small value in restraining the severities of warfare, and one is almost tempted to sympathize with those who affirm that warfare governed by prize ring rules can never be truly and in fact the *ultima ratio* of nations. But it cannot be denied that a great deal of the uninformed outcry about so-called illegal weapons is due to the fact that their critics have not made themselves familiar with the actual text of the Hague Conventions and Regulations.

Enemy Projectiles.

Of the weapons actually used in the war it is not necessary to give all the details. Only those facts are chosen which have some interest or importance for the surgeon. Nor is it possible in all cases to follow up the many changes which were made during the campaign. Here again it is proposed only to note developments which have had some effect upon wounding power.

Rifles.—The rifles used by enemy forces were very similar to each other in make and calibre. On the accompanying table are given some details of their make. It will be observed that in the case of the German Mauser, since the length of the barrel

TABLE I.

Country.	Model.	Calibre in mm.	Length of barrel in inches.	Twist of Rifling.		Muzzle velocity in f/s.	Bullet.				Charge.	
				One turn in inches.	Direction of twist.		Shape of nose.	Envelope.	Weight in grains.	Length in inches.	Propellant.	Weight in grains.
1. Austria-Hungary.	Mannlicher	8	30·12	9·842	Right	2,034	Round	Steel with trace of Copper	244	1·249	Nitro cellulose	42·44
2. Bulgaria ..	Mannlicher	8	30·12	9·842	Right	2,034	Round	Steel with trace of Copper	244	1·249	Nitro cellulose	42·44
3. Germany ..	Mauser ..	8	29·05	9·39	Right	2,882	Pointed	Steel coated with Nickel	154	1·105	Nitro cellulose	48·4
4. Turkey ..	Mauser ..	7·65	29·13	10	Right	2,066	Pointed	Steel coated with Nickel	154	1·105	Nitro cellulose	40·2

is nearly 30 inches, the length of complete twist of the rifling over nine inches, and the muzzle velocity 2,882 feet per second, the actual spin imparted to the bullet is more than 3,000 turns per second.

As regards rapidity of fire, it has been found that with this class of rifle twenty aimed shots can be fired per minute used as a single loader, and forty shots per minute using magazine fire from the hip without aim.

The nature and quantity of the propelling charge is a factor of extreme importance from the point of view of its effect upon the rifling of the barrel, upon which the accuracy of shooting depends. In large-bore rifles firing black powder, pressures in the barrel were not high and the metal was not injuriously affected. If carefully cleaned, a rifle could be used for years and could fire many thousands of rounds without loss of accuracy. It is quite otherwise with the small calibre rifle firing cordite or ballistite. Not only is the very high temperature at which these propellants burn a great cause of erosion, but the pressures are extremely high and the effects, especially towards the breach end, tend to the enlargement of the bore even after a couple of hundred rounds have been fired. Erosion also takes place at the muzzle, but not so rapidly. Experimentally it has been proved that after 12,000 rounds a rifle was " quite unfit for further use." When the bore enlarges in this manner it fails to give the requisite spin and gyroscopic steadiness to the bullet, and the muzzle velocity also falls off to a large extent. It is probable therefore that, with worn rifles, bullets, especially of the pointed type, will be more unsteady, as, for example the German " wire cutting " bullet which is described below.

The machine gun and the various types of automatic rifle are, in all essentials which concern surgery, rifled arms with special arrangements for rapid fire. Their action is automatic and they can fire from 400 to 500 shots per minute, using the service rifle cartridges which are fed to the gun in belts carrying about 250 cartridges. The barrel of the machine gun has a controlled movement in firing both vertically and horizontally, and thus it came about that multiple wounds of the severest type were inflicted by these weapons which were used in immense numbers in the war.

The bullet employed by Germany and her allies in the war was of the type used in the small calibre magazine rifle of the present day. It was composite, consisting of a core either of soft lead or more generally of lead hardened with antimony,

and a casing or envelope of some harder metal, soft steel or iron, or an alloy of copper and nickel. The core was inserted in the rear end of the envelope which was afterwards turned in over the base of the core. The envelope itself was solid drawn, and consequently had a solid point somewhat thicker than the sides. But the feature which gave the bullet its chief ballistic and wounding qualities was its shape. Fig. 1 gives the resistance to air pressure offered by bullets whose points are shaped by making them the intersection of two circles with radii of one, two, three or more times the diameter of the bullet. The first form is hemispherical, the third is the shape of the standard bullet's point, the air resistance of which may be considered as unity

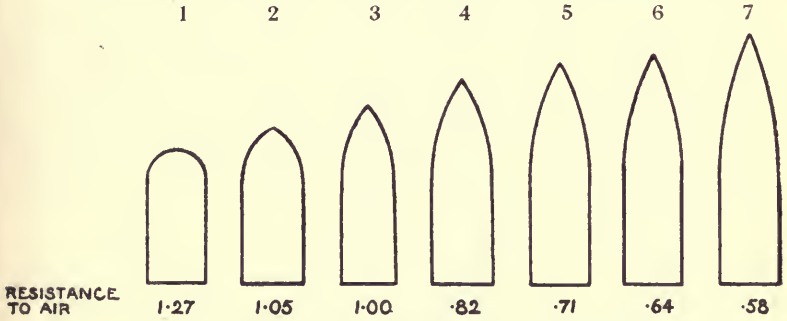


FIG. 1.—Diagram of Bullets showing Air Resistance.

It is found experimentally that the air resistance diminishes if a bullet point is made progressively and regularly sharper in the manner indicated. The result of this lessened resistance is that the pointed bullet " maintains its velocity better and that the trajectory is flatter. In order further to flatten the trajectory at moderate ranges, which are of greater military importance than the extreme ranges, the bullets are made lighter, which allows of a higher muzzle velocity."

To show the comparative velocities at ordinary military ranges of the English Mark VII bullet and the German Spitzegeschoss, the following table may be studied :—

Type of Bullet.	Length in inches.	Weight in grains.	Velocities in f/s.		
			Muzzle.	At 500 yds.	At 1,000 yds.
1. Mark VII. ..	1·28	174	2,420	1,510	1,020
2. Spitzegeschoss ..	1·105	154	2,980	1,780	1,090

It will be seen that at 1,000 yards, in spite of its superior initial velocity, the German bullet enjoys no great advantage over the Mark VII, an effect no doubt of its weighing some 20 grains less.

From a ballistic point of view then the pointed shape is evidently a great advantage. Moreover, as the whole cartridge now weighs less, the infantryman can carry some 150 on his person and can thus meet the more rapid expenditure of the magazine rifle. And finally, as will be shown later, both experimentally and from actual battle experience, the wounds inflicted by the pointed bullet were found to be more severe than those due to the oval tipped bullet.

Besides the ordinary bullet above described the enemy used a number of special bullets; some for use against tanks, some of the so-called "tracer" kind, and so on. Three of these may be mentioned—one which was used for the machine guns on his aeroplanes, and the others in the trenches.

(1) An explosive bullet, a sectional diagram of which is shown in Fig. 2, was composed of the following parts:—

(*a*) A case of thin rolled iron, 3 mm. thick at the sides and 6 mm. at the head.

(*b*) A lining of lead 6 mm. thick at the base which it closes, and extending almost up to the curve of the head.

(*c*) In the head, a cylindrical brass pellet carrying a flat striker point.

(*d*) A percussion cap moving freely in the pellet, but held away from the striker by a spring.

(*e*) Another cylindrical brass pellet below the first one, containing black powder, slow burning.

(*f*) A cupro nickel tube extending to the lead base and containing a mixture of potassium chlorate 56·8 per cent. and antimony sulphide 42·1 per cent.

Experiments were made by the French by firing these bullets from a German rifle at a range of 8 metres against a target composed of eleven half-inch pine planks with four cases filled with bran behind them, each about ten inches thick. One of these bullets penetrated the eleven planks and the first two cases and burst in the middle of the third. The French authorities concluded that these bullets were intended to be explosive and would be valueless either as tracers or smoke producers for observation purposes.

(2) A bullet for wire cutting was a drawn steel cylinder of 7·8 to 7·83 mm. in diameter and 77 to 77·1 mm. in length,

weighing 28·65 to 28·80 grammes. The steel of which it was composed was very mild and could not be tempered. Experiments were made in France with these bullets which suggest

SMALL ARMS BULLET
from captured Zeppelin

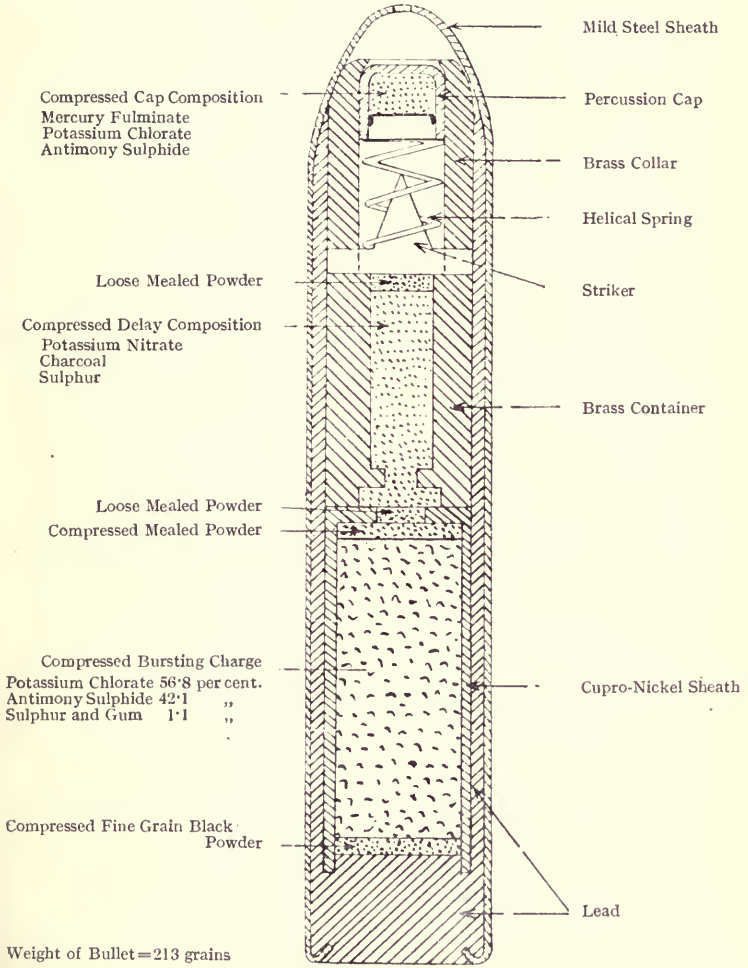


Fig. 2.

that they were used principally for cutting wire at short ranges. The diameter of the bullet being less than that of the bore, they do not take the rifling, and, when fired through paper screens at varying distances from the muzzles, made

GERMAN RIFLE AMMUNITION (DUM DUM).

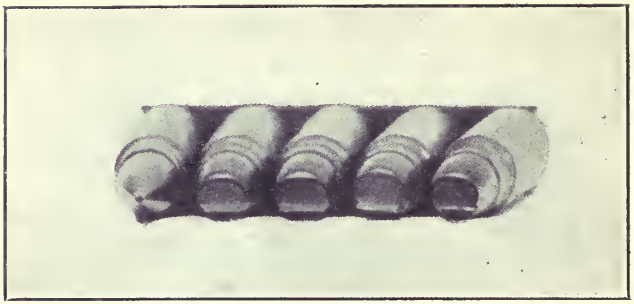


Fig. 3.—End view of bullets.

Fig. 3A.---Clip as received.

holes in many of the screens equal in length to the bullet itself. The experiments showed that the bullets turned over in the air within 10 metres of the muzzle. Such a bullet would no doubt be useful for cutting wire, but it is also calculated to inflict terrible wounds at short ranges.

(3) A perforating bullet, which was intended to perforate the light steel plates protecting the machinery of aeroplanes, consisted of an exterior shell of mild steel lined with lead and containing a central pointed core of hard steel. According to a captured German document this ball, which was known as " SMK," would penetrate a plate of 4·5 mm. in thickness made of nickle chrome steel at 1,400 metres when fired at its normal, and at 900 metres when fired at an angle of 70°. These bullets, though giving much greater penetration, gave less accurate firing at long ranges.

The " K " bullets, in spite of their inferior initial velocity, owing to their greater weight and their stream line form, preserve their velocity longer, and their trajectories would cut those of the " S " bullets again at about 600 metres. The following table gives the comparative weights, charges, and muzzle velocities of these and the ordinary " S " bullet.

Type.	Weight in grammes.	Weight of charge in grammes.	Muzzle velocity in metre seconds.
1. " S " bullet	10·00	3·20	852
2. Explosive	13·90	2·50	(?)
3. Wirecutting	28·65	2·35	368
4. Perforating	11·55	2·90	791

It was also occasionally the practice of the Germans to mutilate the ordinary rifle ammunition so as to expose the lead and transform it into an expanding or Dum Dum bullet. The photograph (Figs. 3 and 3A) is of a clip of German rifle ammunition picked up in Wervic on 17th October, 1918. It seems probable that the cuts have been made with parallel jawed wire cutters.

Artillery.—Guns in common use.—The 7·7 cm. field gun, the 10·5 cm. light field howitzer, and the 15 cm. heavy field howitzer were the weapons with which the greater part of the German artillery was equipped. Some of the particulars of these guns are given in the following table in which several others of the commoner types are included :—

	Calibre.	Weight of H.E. Shell.	Maximum percussion range.
	inches.	lbs.	yds.
3·7 cm. revolver gun	1·46	1	3,280
7·7 cm. field gun	3·03	14·5 to 15·5	9,186
9·0 cm. field gun (old)	3·46	16·5	7,109
10·5 cm. light field howitzer ..	4·13	34·5	7,655
10·0 cm. gun	4·13	39·5	11,264
12·0 cm. gun	4·73	36	7,984
13·0 cm. gun	5·31	88	15
15·0 cm. heavy field howitzer ..	5·89	86 to 93	9,296
21·0 cm. mortar howitzer ..	8·30	183 to 262	10,280

Long Range guns.—A recent feature of German artillery development was the increasing use of long range guns which were usually on railway mountings. The majority of these were naval guns, apparently not of the latest pattern ; the calibres used against the British front included 15 cm., 24 cm. and 38 cm.

The 15 cm. naval gun was the most frequently employed, an ordinary high explosive shell being used at ranges up to 13,000 yards and a high explosive shell with false cap at longer ranges. The maximum range hitherto reported was 18,700 yards.

The 24 cm. naval gun also fired two types of shell, a high explosive shell with a false cap, and an extremely tapered high explosive shell, which was a further development of the false cap type. The maximum range was 27,500 yards.

The 38 cm. naval gun was occasionally employed against the British front, firing a high explosive shell with false cap.

The range of the artillery used by the Germans on the Western Front is illustrated in the diagram prepared during the war by the General Staff, and reproduced here. The diagram was of much value to the medical services in determining the relative zones of safety for medical units. (Fig. 4.)

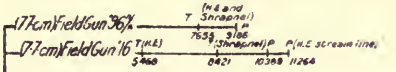
General von Stein considered it essential in September 1916 that the following supplies of ammunition, almost double those deemed adequate early in 1916, should be maintained in the battery positions :—

	Rounds.
Field gun battery	3,000–3,500
Light field howitzer battery ..	3,000
10 cm. gun battery	—
Heavy field howitzer battery ..	1,500 and 300 T gas shells.
21 cm. mortar battery	500

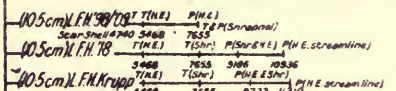
MAXIMUM RANGES OF GERMAN GUNS, HOWITZERS & MORTARS.

FIELD ARTILLERY

(a) FIELD GUNS

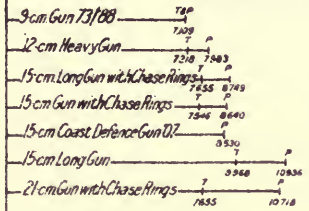


(b) LIGHT FIELD HOWITZERS

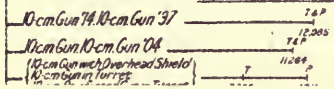


FOOT ARTILLERY

(a) MEDIUM RANGE GUNS



(b) HIGH VELOCITY & LONG RANGE GUNS



FEATURES OF SPECIAL INTEREST.

1. *The introduction of new patterns of guns, howitzers and shell, by which the range of the field artillery has been considerably increased.*

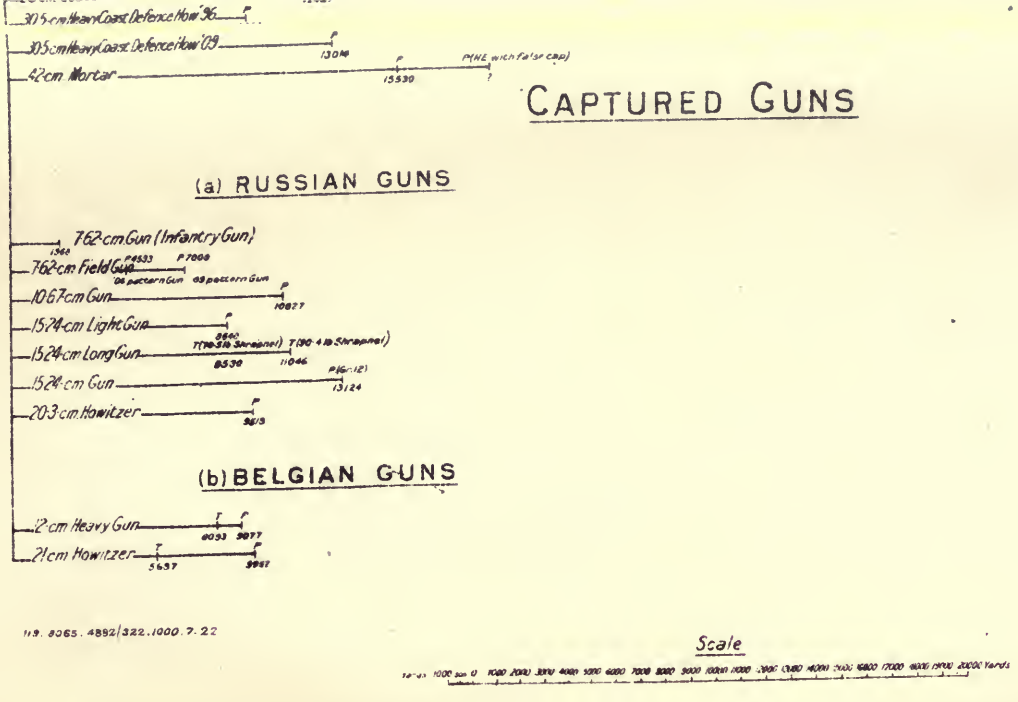
2. *The increased range of some of the high-velocity guns, due to the adoption of stream-line shell (with and without false caps).*

3. *The introduction of howitzer shell (15-c.m. and 42-c.m.) with false caps*

FIG. 4.

(c) HEAVY FIELD HOWITZERS & MORTARS
(15cm) Heavy Field Howitzer
(15cm) " " 02
(15cm) " " 13
(15cm) Long Heavy Field Howitzer 32
(15cm) Howitzer in Turret
21cm Mortar
21cm) Mortar
21cm) Long Mortar
28cm Coast Defence Howitzer
10cm Coast Defence Gun
10cm Coast Defence Gun on Wheeled Carriage
10.5cm Q.F. Naval Gun L/35
13cm Gun
15cm Gun with Overhead Shield
15cm Experimental Gun on Wheeled Carriage
15cm Gun '16
15cm Q.F. Naval Gun L/30
15cm Q.F. Naval Gun L/40
17cm Gun on Wheeled Carriage
21cm Q.F. Naval Gun L/45
24cm Naval Gun
35·6cm Coast Defence Gun
38cm Naval Gun
Shell with False cap
Shell with False cap and clockwork fuse
P(HE) with False cap
P(HE) with False cap and clockwork fuse
P(HE) with False cap & Electrical fuse
P(HE) with False cap & Electrical fuse (Pattern W. E.)
P(HE) with False cap & H.E. with False cap
P(Base ejection) & H.E. with False cap
Shell with False cap
Shell with clockwork fuse
P(HE) with False cap
P(HE) with False cap and clockwork fuse
P(HE) with False cap
P(HE) with False cap
P(HE) with False cap

CAPTURED GUNS



Maximum Ranges in Yards.
T - with time fuze.
P - with percussion fuze.

H.P. 8065. 4892/322.1000. 7. 22

Scale

FIG. 4.

During the first period of the Somme offensive, he reported his average daily expenditure to have been :—

Rounds Fired.	Field gun battery.	Light field howitzer battery.	Heavy field howitzer battery.	21 cm. mortar battery (two mortars).
(*a*) During artillery duel from 24th to 30th June, 1916.	1,500	1,050	520	200
(*b*) 1st July, day of infantry attack.	2,270	1,800	940	400
(*c*) Specially high expenditure by individual batteries on individual days.	4,500	3,000	1,200	500

Trench Mortars.—The following were the trench mortars in common use :—

Trench Mortars.	Cal. inches.	Weight of H.E. projectile.	Range.
		lbs.	yds.
25 cm. heavy	9·84	139	262–919
		210	164–514
17 cm. medium	6·69	100	116–1006
7·5 cm. light	2·95	10	175–1148
9·2 Lanz	3·58	8·7	137–492
		* 44	38–290
24 cm. heavy Ladwigswerfer ..	9·45	66	27–208
		88	22–175
Granatenwerfer (stick bomb thrower).	—	4	66–208

Pneumatic Trench Mortars.	Weight of H.E. projectile.	Weight of H.E. bursting charge.	Range.
	lbs.	lbs.	yds.
15 cm. Press luft	143	44	110–492
10 cm. Press luft	13	3	110–547

Rate of fire, one round per minute.

* These were the thin-walled projectiles usually known as "rum jars." Similar projectiles, cylindrical in shape and known as "oilcans," were fired from various types of extemporized mortars. The penetrative power of all these projectiles was practically nil, but owing to the size of the charge their moral effect was great.

This long list of artillery projectiles is by no means exhaustive. Trench warfare produced projecting machines of many kinds for throwing parcels of high explosive for short distances. The catapult was represented among these. No mention has been made of the many types of gun which threw gas shells, as it is thought that the resulting type of injury interests the medical side more than the surgical. As a commentary on this amazing range and amount of artillery armament, it may be remarked that the multiplicity of types shows that there was, so to speak, a gun for every emergency, that is, an immense increase in the total number of guns used; that the expenditure of ammunition was beyond all precedent; and that the bulk of the common shell had high explosive as a bursting charge.

Bombs.—The aircraft bombs were relatively thin-walled missiles loaded with a large charge of high explosive, and their wounding effects were due partly to the mere disruptive effect of their explosion, partly to the secondary missiles, splinters of wood or stone set in motion by their explosion, and partly to the razor-edged slices of metal, composed as a rule of shell steel of which their bodies are composed.

Grenades.—Numerous rifle and hand grenades were used in trench warfare and acted partly by the direct effects of their explosion or by the action of the fragments into which the tin or iron casing was blown. These were often very small and had little power of penetration. Fragments of the " serrated " varieties were larger and more dangerous. But the direct effect of the explosion was the main danger. Rifle grenades were disused owing to want of accuracy. Of hand grenades in common use, the cylindrical grenade with handle (*Stielhandgranate*,sometimes known as the " jampot and stick grenade "), the " ball hand grenade " (*Kugelhandgranate*), both of the time variety, and the " disc percussion grenade " (*Diskushandgranate*), were retained. A new hand grenade, the " egg " (*Eierhandgranate*), made its appearance and was used in considerable quantities. This was a small grenade of the shape and about the size of a pullet's egg. It weighed only 11 oz. and could be thrown about 50 yards; but its effect, as it was only filled with powder and fired without a detonator, was very small.

The Germans did not seem very satisfied with their disc percussion grenade, which was in fact somewhat dangerous to handle and very dangerous to pick up, if blind. Attempts were made to convert the time cylindrical grenade with handle into a percussion pattern.

Mode of Action of Projectiles

In dealing with the mode of action of projectiles it is at once evident that the rifle bullet is in a class by itself. No greater contrast could be presented than the more or less haphazard open-air explosion of a high explosive or shrapnel shell or bomb, and the ordered and controlled deadliness of a rifle bullet. Moral effect has always been an important factor with the artillery arm, and it is only when used in immense and crushing concentration that its action is as killing as that of well-aimed rifle fire. The circumstances of the war, the stabilization of battle so as to resemble siege conditions, gave an entirely unaccustomed predominance to the artillery arm, both in number and weight. Under the usual conditions of open warfare this would be impossible, and the rifle and machine gun would regain their proper value.

Rifle bullets.—It is of importance therefore for the surgeon to have some acquaintance with those characteristics of the rifle bullet which mainly influence its wounding powers, and are due to its make and behaviour in flight. Of the actual movements of a bullet as determined experimentally it will be possible to give only a summary. The dynamics of a smooth elongated body of this nature moving in the line of its long axis with an initial velocity of 2,600 to 2,800 feet per second, rotating between 3,000 and 4,000 times per second on its long axis, and of a length nearly four times its diameter, may be mathematically investigated and its characteristic flight foretold, but the results could only be true while conditions remained constant. The propellant charge must be correct to a grain, the material of the metal so nearly homogeneous that the centre of gravity and centre of form lie in the long axial line, no alteration of form must take place on discharge, and the bore of the rifle must undergo no change. Whereas in practice every one of these conditions is found to vary, it results that most bullets do, from imperfections of manufacture and other causes, show irregularities of flight which have been the subject of investigation by many workers. In the well-known work of Dr. F. W. Mann of America, it is stated that of the following movements not every bullet shows them all but some bullets do and all bullets will show a majority of them :—

(1) Movement of translation, due to gas pressure from exploding powder.

(2) Spin, due to spirally grooved rifle bore. The spin is a factor of such importance that it has been found experimentally that every kind of propellant, every bore of rifle, every weight and shape of bullet requires a definite pitch of rifling to obtain the best results.

(3) Trajectory movement, due to the effect of gravity and air resistance, which cause the path of the projectile to be a modified parabola.

(4) Gyration produced in the spinning bullet by the application of a constant force continually acting at right angles to the movement of gyration. This force is the air pressure at or near the bullet's point. Most bullets being more or less unbalanced begin to develop a "tip" immediately upon their exit from the muzzle and the deflected point is at once acted upon by the air pressure due to the movement of translation, and so develops a gyration, each phase of which is complete in about 50 feet.

(5) Oscillation, produced in a spinning bullet by a temporary force which has been suddenly applied and then removed. This temporary force arises as follows. In the rifle barrel the centre of gravity of an unbalanced bullet (that is, a bullet in which the centre of gravity is outside the axis of rotation) must take a spiral path round its axis of rotation, but the moment it is released from the muzzle the centre of gravity flies off, like a stone released from a sling, in a line which is the tangent to the bore spiral, and thus a sudden motion is imparted to the hinder end of the axis of rotation of the bullet, and at right angles to it. This produces an oscillation each phase of which is completed in about 9–10 feet.

(6) Point deflection. Since the bullet with a "tip" is not flying in the direction of its long axis, it has a motion which may be properly termed point deflection, due to the glancing of the bullet as a whole on the air pressure, this pressure being more pronounced on one side than the other.

(7) Centre of gravity spiral, in rifle bore. If the centre of gravity is not in the axial line it describes a spiral round the the axial line in passing along the barrel. The importance of this movement appears under oscillation.

(8) Centre of form spiral in the air. The centre of form of an unbalanced bullet, which is obliged to make a straight flight in the rifle bore, begins to make a circle round the centre of gravity and consequently a spiral flight immediately upon its exit from the muzzle. This movement is identical with that which causes the hum of a spinning top.

(9) Gyratory or air spiral. Because of the gyratory movement of the bullet, the direction of its long axis continually changes round the line of the bullet's flight, and because the deflected point must follow in the direction towards which it is pointing or towards the direction of the bullet's axis due to air pressure, it causes the tipping bullet to make a spiral flight. Since the tipping bullet due to point deflection flies as a whole in a spiral after leaving the muzzle, there is this spiral joining itself on to the smaller spiral made by the centre of gravity in the bore within a few feet of its muzzle exit, which may still further increase the deflection from the line of fire.

(10) Wind drift. A change of direction due to the bullet being carried along by the wind.

(11) Wind deflection. Wind drift cannot take place without some pressure on the bullet which will not only move the bullet as a whole but will cause a slight deflection, deflection being due to rotation, *i.e.*, the bullet rolls on the side of increased pressure.

(12) Trajectory deflection, improperly called drift. Because of gravitation the bullet has a trajectory, and this motion combined with air pressure causes deflection of the bullet to the left if the twist of the rifling grooves be left-handed. It is a motion, one element of which is skin friction due to partial rolling and slipping of the bullet upon increased air pressure on its under side, or that side which is presented towards the centre of the earth. This increased air pressure, according to present works on ballistics, is partly due to falling of the bullet through the air in making its trajectory curve, but more largely to its axis not being in the line of this curve or line of flight but standing above it. For example, when a bullet is fired in a horizontal plane its axis of spin remains horizontal, while its trajectory almost at once begins to make a curve below the horizontal plane. Thus the bullet becomes a tipper and like all tipping bullets begins to gyrate, due to air pressure on its point. The axis of gyration tries to keep itself in line with the curve of the trajectory but fails because this latter is constantly becoming more curved. Thus the bullet receives greater pressure on the side presenting downwards. This raises the bullet in its flight and allows it to roll on the increasing air pressure below.

(13) Tumble. If a bullet does not "tip" sufficiently to tumble it tends to follow its point, thus making a spiral flight. If it tips more than six degrees, according to some authorities it is liable to tumble and be lost.

Dr. Mann's results, which are rather difficult to summarize intelligibly, have been accepted generally as correct and go to show that the majority of bullets do not take an absolutely straight course in their flight, but it has to be remembered that all these deviations from the line of flight are very small. For example, the " bore spiral " has a diameter varying from two or three thousandths of an inch to a fraction of a thousandth in diameter, and a pitch of 12 inches, and the " air spiral " has a diameter of five-sixteenths of an inch and a pitch of 45 feet. Nevertheless, in certain cases it must be admitted that the bullet may not be mathematically point-on when it strikes. Speaking of the pointed bullet, Dr. Mann says that it " has practically lost its tip when the 100 yard screen is reached," but not until it has developed " the same error and in the same direction as all other bullets that we have recorded."

Now the significance of any form of irregular flight is that with an elongated bullet, if on striking it changes from a small to a large striking surface, if instead of proceeding end-on through the body, it turns sideways, the destructive effects produced are likely to be very much greater. The so-called " expanding " bullet owes its efficiency to this property of changing from a small to a large striking surface. When small-bore bullets were first introduced they were made with a blunt tip and a long cylindrical body as compared to the length of the conical tip. These bullets were found to penetrate the body, both soft parts and in many cases even bone itself, with clean punctures and little destruction, and it was only at short ranges that the disruptive effects at the exit, which were incorrectly called " explosive," were noted. With the pointed bullet, on the other hand, experience showed that clean perforations were relatively uncommon, and, on the contrary, disruptive effects were common up to the greatly increased ranges. And the question arose as to what caused this difference. Can irregular flight in a rifle bullet suffice to produce the increase of area on impact, which is the essence of the expanding bullet's action, or is the destructive effect due to some other factor? Those who would explain the action of the pointed bullet by its unsteady flight draw attention to the fact that the centre of gravity of the bullet lies some distance behind the centre of its long axis, so that the arm of the couple which tends to turn it on its short axis on impact is much longer than it would be if the centre of gravity were nearer the centre of the long axis (Fig. 5); that clean perforations might naturally be expected to be rare, since the clean perforation

could only occur at those rare moments when the long axis of the oscillating, gyrating bullet happened to be for a small fraction of a time in the line of flight, whereas explosive exits would be the rule at medium ranges; and, finally, that in cases of multiple wounds by single bullets the extent of the damage and the key-holing of the cutaneous structures afford abundant evidence that the pointed bullet actually does turn on impact. Turning, however, does not explain all the facts. If instability alone accounted for explosive wounds, signs of disruption would be visible in all wounds in which the bullet has sufficient remaining velocity to tear up the tissues at all, at much greater ranges in fact than those at which they are actually seen. And in the view of some small arm experts the normal bullet, to use the words of one expert, " does not wobble appreciably."

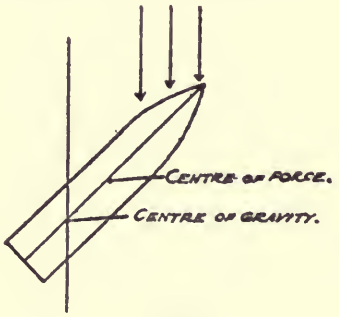


Fig. 5.

He also says " No doctor in the absence of direct experimental evidence is entitled to say that the gravity of a wound is due to the pointed bullet turning over and over in the cadaver. It is a physical impossibility, I believe. So that I think you may take it as an established experimental fact that the pointed bullet goes to sleep like a top in its flight, at any rate for the first mile. In *long range barrage work* the bullet, however, may be flying asleep but with its long axis 20° to 30° out of its trajectory, and so makes an oval hole on hitting. We actually have fired all the bullets used in this war through Mann screens and they are normally quite steady. But if a *very worn barrel* is used we get what is known as B.S.O. (bullet side on). The bullet never takes the rifling but floats down the bore in a stream of gas and emerges with no spin. It travels point first a few yards, perhaps 10 to 20, and then goes head over heels. It loses velocity rapidly and probably has an extreme range of half a mile or so." In the opinion

of this expert the normal bullet (that is, the ordinary jacketted bullet as manufactured) is not sufficiently unsteady to add to the gravity of a wound from that cause alone. It is only when it is abnormal in make or when the circumstances in which it is fired are abnormal that it is unsteady enough for mischief.

There is then another factor which must be considered to explain explosive wounds, and here again expert opinion may be quoted :— " Explosive wounds are due to unsteadiness. I feel sure that a 'burst' rabbit, or 'brains all over the wall' are effects due solely to *velocity*. Sir Samuel Baker never, I believe, records an instance, and the normal muzzle velocity of black powder rifles was about 1,400 foot seconds. With double powder charge, perhaps, 1,800 foot seconds was the high limit, and all these ball rifles lost velocity at the rate of 500 foot seconds per 100 yards of range. Explosive effects (burst rabbits) were first observed, I understand, in England when the Roumanian Mannlicher was introduced for stalking. Men shot at deer and rabbits and 'burst' them to their intense surprise. The muzzle velocity was 2,300 foot seconds, falling 100 foot seconds per 100 yards. Many men had the Mark VI ·303, muzzle velocity 2,000 foot seconds, for stalking and had not burst their game. The 'bursts' occurred with solid-nosed bullets and were not peculiar to soft-nosed bullets. The horrible wound of a soft-nosed bullet can be best accounted for by the mushrooming and break-up of the bullet itself. In the Boer War explosive wounds were noticed, I believe, when the head was hit at short range by a Boer rifle, but not with the ·303 Mark VI.* In this war both the German and the ·303 Mark VII bullet gave explosive effects at 200 yards when the brain was hit and other parts also." In this expert's opinion it is the velocity which counts in wounding powers of the higher order. And this is what might be expected when the striking energy of the missile is considered. This is expressed by the formula $\frac{w.v^2}{2g}$ by which it is clear that of the two factors, weight and velocity, the latter is the more important, and that a large diminution of weight can be more than made up for by suitable increase in muzzle velocity. It would seem, too, that the critical velocity to produce explosive effect is somewhere in the neighbourhood of 2,100 foot seconds, and it has been suggested that the rush of air which follows in the wake of a bullet with a velocity which has been likened to " cavitation " velocity in air—that is,

* There are no records confirming this observation, but it may be true.

the velocity with which air rushes in to fill a vacuum—may help to produce disruptive effects. One may go further indeed and speculate whether, at any rate in some of the gas and fluid containing structures of the body, there may not be a commotion of the tissues in the wake of a bullet comparable to "cavitation" effects in air, generated in the rear of a projectile moving at the rate of over 2,000 foot seconds and competent to produce a blowing out effect at the exit.

Professor A. M. Worthington, in his "Study of Splashes," gives some remarkable information as to visible physical results when a missile is dropped into a fluid medium, using the term in its widest sense. He used fluids of such varying viscosity as petroleum, water, milk and glycerin. He shows how a rough sphere dropped from a low altitude into a fluid throws the fluid with which it comes into contact upwards in the form of a circular crater which subsequently closes over and forms an air bubble, how a column of air follows the sphere downwards, and subsequently breaks up into bubbles some of which follow the sphere, and how the general level of the liquid surface is slightly raised even at a great distance from the place of the splash. When the height from which the sphere is dropped is increased and its velocity is greater, a downward jet of fluid is formed which shoots down behind the sphere in pursuit of it. The sphere in fact acts as a sort of piston, sucking in the bubble formed by the closing of the crater produced at the impact of the sphere on the fluid surface, which is driven down by the greater atmospheric pressure above. The jet may pass down through the air tube in the wake of the sphere and even strike the top of the descending sphere. When a projectile hits an iron plate, there appears the same slight upheaval of the neighbouring surface and the same crater, from which it is inferred that under immense and suddenly applied pressure the steel has behaved like a liquid. Professor Worthington's projectiles moved with a velocity of from 24 to 36 feet per second on impact. What results might have been observed at higher velocities it is impossible to say. Nor is it fair to press too far the analogy of his results with those of bullet impact. But at least it may be inferred from them that a war missile does something more than merely perforate the tissues like a trocar, that there is a commotion of the tissues pierced which may be exceedingly destructive, the tissues tearing themselves, as it were, in their endeavour to follow the bullet, and that these effects are not confined to the parts struck but radiate far beyond them.

Expert opinion then seems to have decided that velocity is the main cause of the acknowledged severity of wounds by the light pointed bullet, but at the same time it is difficult to believe that instability has nothing to do with it, especially after any considerable experience of wounds in warfare. It is possible that the results observed are due to a combination of the two factors in many instances. During the trench warfare period of fighting the ranges at which wounds were inflicted by rifle bullets were short, and it is probable that ricochet shots were extremely common. Delorme in his "War Surgery" says, "we rely on the effects of ricochetted bullets, a ricochet occurring in the proportion of 1 to 3 bullets discharged." At short ranges a ricochetting bullet passing through sand or loose earth would not necessarily lose a great deal of velocity, but would almost certainly develop "wobble." So that if Delorme's estimate can be taken as approximately correct, both factors of instability and velocity are in constant action.

With the pointed bullet the effect of shape as a wounding factor is very important. The pointed bullet most certainly can and does glance at any obstruction, and in a very curious way. A clean puncture is the usual hole made in wood or any artificial stopbutt used for the recovery of the bullet, when the impact is at a right angle. When the impact is at an angle there is a great chance of the bullet bending or breaking up, or glancing in the most unexpected manner. The sharper the point the greater are the chances of an extraordinary hole. Artillery projectiles of a pointed shape show the same liability to deflection. It has been said that no gunner will fire a non-deformable pointed projectile at an earth bank if he knows his business, unless he is a mile or so behind the bank. It may "turn turtle" in the bank and come out right backwards. A flat-headed shot always lodges in the bank. The holes which the pointed shots make in the bank show that they keep their noses fairly well in line with their direction. One of the objections to the light pointed bullet in big game shooting is that it is very liable to be deflected by any dense bone and so miss vital structures. On the other hand, as has already been shown, the shape is of great importance as a factor in overcoming air resistance, and so enabling the bullet to start with a high muzzle velocity and maintain a high velocity over useful military ranges.

The clean perforation and the explosive exit are at opposite poles as regards severity in rifle bullet wounds, and what has

been said above, while perhaps it cannot make clear the exact mechanism of their causation, at any rate suggests a fairly satisfactory explanation of their occurrence. But the explosive exit is not always due to one and the same cause. Among other hypotheses which have been put forward to explain its appearance there is one which supposes that the pad of air in front of the nose of the bullet, which is clearly seen in Professor Boys' photographs of flying bullets, expands in some fashion in the tissues and blows them out. Another takes the view that the high rotation of the bullet is an important factor in causing disruption of the tissues. But there are two theories which better deserve mention because they are based upon normal physical phenomena and may in many cases explain disruptive effects. The " hydraulic " theory supposes that when body structures containing water or other fluid are struck by a bullet the same effect is produced as when a lead pot containing water is fired at. The lead pot is burst completely, since the fluid conveys to all parts of its interior surface the multiplied effect of the bullet's stroke upon one small area. There is no doubt that effects of a similar kind have been observed in a full stomach and bladder and even in the brain, but bursts of this kind are by no means invariably the result of perforation as ought to be the case if the hydraulic theory were true. Still it is impossible altogether to rule them out as a type of disruptive effects. The other theory is based upon the observed fact that when a large bone is hit at short range the bone fragments become secondary missiles and, endowed with communicated energy from the bullet, plough up the tissues and even blow away large areas of skin. It is supposed that this energizing of tissue particles may even extend to the soft parts and so cause bursting of solid viscera like the liver and spleen. This is perhaps to push the analogy rather beyond probability. It will be seen later that those who have studied wounds of large solid viscera adopt the view that the laceration is the result of high velocity. Professor Shattock says :—" From the more strictly pathological standpoint the new factor introduced into gunshot injuries, as injuries, is the velocity of the missile."

Two other physical characteristics of bullets have to be mentioned. The heating of the bullet is natural enough. It is exposed to the super-heated gases which arise from nitrocellulose and nitro-glycerine compounds on explosion ; it is scraped along 30 in. of barrel with sufficient friction to engrave its sides ; it is fired from a barrel which is often hot from

previous shots, and a part or the whole of its kinetic energy becomes transformed into heat upon impact. Many stories are heard from wounded soldiers of bullets which singed their clothes and blistered their skin. Moreover, examination of many bullets after firing shows a ring of minute beads of lead at the base where the jacket turns over the lead. Friction has evidently caused heat enough to melt the superficial layers of lead, though it is questionable if it sets up enough heat to warm the whole mass of the bullet appreciably. At any rate bullets fired into sawdust do not cause any charring. According to La Garde they do not melt butter or ignite gunpowder, nor is the development of heat sufficient to sterilize the bullet. When a bullet is really hot to handle it is almost certainly a ricochet, part of whose kinetic energy has been transformed into heat.

The sterility of the bullet has been the subject of much experimentation. The base and cylindrical sides are almost certainly sterile after firing, but the pointed bullet has a large area in front of its cylindrical portion which cannot be surgically clean. Punctured wounds by the blunt-nosed bullet are only relatively non-infective. Their reputation as clean healing wounds was due to the power of the tissues to destroy a mild infection. It would probably be true to say that no bullet is bacteriologically clean, even when it reaches the skin directly. When it is remembered that it passes through muddy and body-soiled clothing and finally through the unwashed skin, all debate as to its sterility must be abandoned. Delorme remarks, however, that in passing through the skin and superficial tissues this bullet apparently rapidly wipes itself clean. The same observation was made by Dr. Mann when firing bullets through a series of screens. The first screen wiped off the major part of the blackening from the bullet. And as rifle bullets show a remarkable power of penetrating clothing without carrying portions into the wound, infection in their case is not so deeply implanted as is the case with shell fragments and shrapnel bullets, but is more superficial and, therefore, amenable to surgical treatment.

Artillery projectiles, bombs and grenade fragments.—Turning next to shell fragments, shrapnel bullets and fragments of aircraft bombs and hand grenades, it is to be noted that they differ in their effects more from the rifle bullet than they do from each other. They are all of the same class, haphazard in action, and, as compared with rifle bullets, lacking in velocity, that is, in penetrative power. It is true that in

the case of large shell or bomb fragments the striking energy $\frac{w.v^2}{2g}$ is sometimes very great owing to the weight of the fragments, and that the resulting wounds are very severe, but the average size of missiles due to fragmentation of field gun shells or of hand grenades is seldom large enough to cause fatal injury except in the immediate neighbourhood of the explosion, or unless they strike a vital part,* and their chief danger is that they almost invariably carry in with them fragments of clothing and thus render wounds septic. This class of wound assumed an importance in the war which was misleading. The usual proportion of shell to rifle bullet wound in the wars of the last 50 years has been about 10 per cent. In the Russo-Japanese War at the battles of Liao Yang, Sha Ho and Mukden taken together, there were 10 per cent. of wounded by shell out of over 29,000 wounded by all arms. It is acknowledged that this proportion rises in sieges, and in the war where the stabilized line of battle approximated to siege work this proportion was certainly surpassed, putting aside the fact that the numerical increase of gun power was unusually great and that aircraft bombs and hand grenades were used in large numbers.

The following table gives the regional incidence in trench warfare of wounds received into the casualty clearing stations of three armies in a fortnight, and the nature of the missiles causing them. It is often so difficult, however, to be certain of the missile that the table cannot be considered quite correct. The higher degrees of injury will nearly always in the absence of the missile be put down to shell fragments. But taking this table for what it is worth, and remembering the siege-like conditions which the front line had assumed at that time in Flanders and Picardy, it is seen that rather over 27 per cent. of all wounds were due to bullets, and rather less than 73 per cent. to shells, trench mortars, bombs and grenades. Moreover, of the 897 bullet wounds, about half are classed as severe, whereas in the case of the shell wounds the proportion of severe to slight is roughly as 3 to 4. In this remarkable and unusual phase of warfare, therefore, shell wounds, being nearly three to one wound by rifle bullets, necessarily take rank as type wounds.

In open warfare, however, the fact still remains that the rifle bullet does nearly as much wounding as the artillery projectile, and there is no doubt that from the point of view of septic infection the rifle bullet is far less dangerous than the shell

* See illustration of fragmentation patterns, facing pp. 30 and 31.

TABLE II.

Regional incidence of all wounds in cases admitted into casualty clearing stations of 1st, 2nd, and 3rd Armies during 14 days of trench warfare—approximately 14th to 27th December 1915

	Total.		Total.	Head. Face. Neck.	Shoulder and Back.	Chest, Front and Sides.	Abdomen, Front and Sides.	Buttocks	Thighs.	Legs.	Feet.	Arms.	Forearms and elbows.	Hands.	Multiple Regions.
Bullets ..	897	M	423	106	29	40	36	15	42	51	15	32	21	20	16
		N	474	106	45	20	9	17	68	44	16	47	34	42	26
Shells and Trench Mortars.	2,171	M	879	159	118	67	36	34	87	139	27	77	16	18	101
		N	1,292	341	159	32	16	71	107	152	56	132	54	84	88
Bombs and Grenades.	217	M	81	14	2	6	3	1	4	10	—	9	—	4	28
		N	136	35	7	2	—	5	8	18	10	10	4	10	27
Total ..	3,285	M	1,383	279	149	113	75	50	133	200	42	118	37	42	145
		N	1,902	482	211	54	25	93	183	214	82	189	92	136	141
Total by regions			3,285	761	360	167	100	143	316	414	124	307	129	178	286

M.=Severe wounds. N.=Slight wounds.

fragment. The surgical literature of previous wars recorded this fact, but its real importance only appeared when shell wounds became as frequent as or more frequent than rifle bullet wounds. The septic shell wound soon assumed an importance which made surgeons forget the possibility of a relatively clean bullet wound and assume that all missile wounds were equally septic. So, no doubt, they were, under the circumstances in France and Flanders, but the results noted in Manchuria in the Russo-Japanese War and in Egypt and Palestine recently were by no means the same, and it is notorious that the observations of the South African War were misleading because based upon wounds caused by bullets in very aseptic surroundings.

Generally speaking, it may be said that wounds of the shrapnel and shell fragment class lack penetration, and owe their effects, when they do show conspicuous severity, more to their weight element than to their velocity element; that fragments frequently lodge and carry in with them to their site of impaction portions of clothing and other foreign bodies; that they are almost invariably septic; that they are frequently multiple; and that they do not show "explosive" results.

As regards the mechanism of their flight, the following facts concerning artillery projectiles are of interest.*

The shrapnel bullet has a maximum effective flight of little more than 150 metres (162 yards).

It starts from the bursting point of the shell, so that its velocity is that of the shell. It is thus free from the influence of rifling.

The initial velocity of the shrapnel shell is 500 to 580 metres per second, decreasing from 420 metres per second to 250 metres per second as the range increases from 1 to 4 kilometres. A certain velocity is imparted by the explosion of the charge in the shell, the resultant velocity of the bullets being 350–520 metres per second.

Bullets at the farthest limits of the "cone of dispersion" have a velocity of 180 metres per second at a distance of 150 to 200 metres from the bursting point. They also have a striking force of 15 kilograms per square centimetre, sufficient to place a man *hors de combat*. Double that amount is required for a horse.

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* Translated from the *Revue Militaire Suisse* of January 1917 by Captain G. de L. Landon, R.F.A.

The following table gives the principal ballistic data of three modern types of shrapnel shell, and the average opening of the " cone of dispersion."

TABLE III.

Ballistic data (field gun).	German 77 mm. Mod. 96n A. Krupp.	Swiss 75 mm. 1905 Krupp.	French 75 mm. 1887 Deport St. Claire Deville.
Initial velocity at 25 m. from muzzle in metres per sec.	465	485	529
Shrapnel shell :—			
Total weight	6·850 kg.	6·350 kg.	7·240 kg.
Weight of charge (internal).. ..	·57 kg.	—	·7 kg.
Spherical bullets— ..			
Number	300	210	298
Weight	10 grms.	12·5 grms.	12 grms.
Diameter	12·2 mm.	31·1 mm.	12·9 mm.
Average opening of " cone of dispersion " at 4,000 metres.	9° 30′	8° 22′	8° 37′

Guns of medium calibre (120 mm. to 155 mm.) fire shrapnel shells containing 250 to 500 bullets weighing 20 to 65 grammes in place of 300 weighing 9 to 13 grammes.

From the tactical and ballistic point of view the question is what is the maximum remaining striking force necessary to place men and horses *hors de combat.* The three vulnerable zones of mortal, severe and slight wounds are, according to Colonel Bircher, as 30 to 25 to 45 for shrapnel.

TABLE IV.

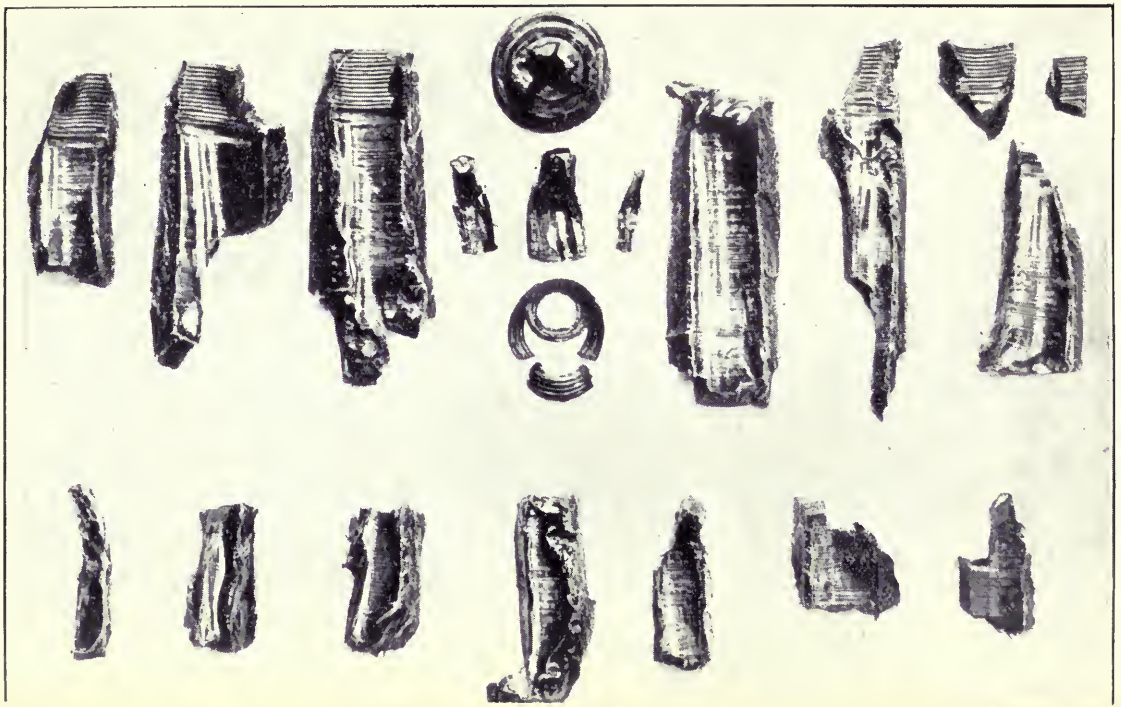
Striking force in foot lbs. per square inch.	Wounds.	
	Man.	Horse.
(*a*) Less than 10·8 ft. lbs. ..	Contusions.	—
(*b*) 10·8 to 21·6 ft. lbs.	Wounds more or less deep in soft parts.	Contusions.
(*c*) 21·6 to 43·2 ft. lbs.	Bone bruised.	Wounds more or less deep in soft parts.
(*d*) 81·2 ft. lbs.	Bones broken and pierced.	Bones cracked.
(*e*) 162 ft. lbs.	—	Bones broken and pierced.

To face page 30.

FRAGMENTATION OF 18-Pdr. MARK III SHELL.

Explosion Only.

Scale of Inches.



With regard to shell, bomb and grenade fragments there are two types of high explosive shell. One has a thin casing and carries a heavy charge (*e.g.*, 825 grms. of melinite). A dense fragmentation takes place on detonation into about 2,000 small splinters with an initial velocity of 1,200 metres per second The other has a thick casing and a small charge (*e.g.*, 135 grms. of

FRAGMENTS ILLUSTRATING VIOLENCE PRODUCED BY EXPLOSION AND DETONATION.

SHELL:—18-PDR. MARK III.

EXPLOSION. DETONATION.

Fig. 8.—View of Outer Wall.

picric acid). On detonation about 500 fragments are produced of varying weight (10 to 200 grms.) with relatively small initial velocity (300 to 400 metres per second). The French 75 mm. shell is an example of the first, and the German 77 mm. shell of the second.

Some photographs are given to illustrate the degree of

FRAGMENTS ILLUSTRATING VIOLENCE PRODUCED BY EXPLOSION AND DETONATION.

SHELL:—18-PDR. MARK III.

EXPLOSION. DETONATION.

Fig. 9.—View of Inner Wall.

fragmentation of a high explosive shell. The English 18-pounder shell is taken and the effect is shown of complete detonation (Fig. 6) and of explosion only (Fig. 7), and the manner in which complete detonation alters the shape of the fragments, leaving them with edges which are ragged and sharp cutting (Figs. 8 and 9), whereas incomplete detonation or explosion leaves them blunt and more regular.

A description is given in Appendix C of the size and shape of fragments of aeroplane bombs. They are usually large and ragged, but the chief effect is due to the local effect of the detonation of high explosive with which they are filled.

In the case of hand and rifle grenades of all kinds the effect again is chiefly due to their explosion and not so much to the size or penetration of the fragments into which they break up. The latter lose velocity very rapidly and often do no more than penetrate the skin, causing very numerous wounds of a characteristic kind. In an enclosed space like a trench, the effect is severe, but the interposition of a traverse renders their action more or less nugatory.

From what has been said above, it is clear that in the case of shrapnel the effect of the shell burst depends to a large extent on the range and the height of the shell at the point of detonation. The bullets have the remaining velocity of the shell at the point of detonation, plus a certain impulse due to the bursting charge in the shell. The longer the range, therefore, the less the remaining velocity. Similarly, the greater the height of the shell burst, the less will be the striking velocity of the bullets, though owing to the opening out of the "cone of dispersion" they will cover a greater extent of ground. The nosepiece of the shell containing the fuze, the base and sides of the shell, which attain a thickness of about 5 to 15 mm. and which usually also undergo fragmentation by the force of the explosion, provide additional missiles of some importance.

The danger area surrounding the detonation of high explosive shell is dependent on many factors, such as :—

(1) Whether fired by time or percussion fuze. If the former, the effects depend on the height of the point of explosion; if the latter, upon the angle of impact and the nature of the object struck, whether hard or soft. A shell impinging on soft earth forms an excavation in which its fragments are retained, but when it strikes a hard object such as a rock or concrete, it may add to its own fragments many pieces broken off.

(2) Whether the shell bursts close to its objective. The effect of high explosive is very localized and shell fragments rapidly lose their initial velocity. In the immediate vicinity of the explosion the effects of the shell fragments are altogether lost in the disruption caused by the explosion itself. This applies to all forms of high explosive, and is seen particularly when explosion takes place in a confined space. Photographs of a 12-inch wire-wound gun burst by a charge of cordite show the gun cut completely in two, the muzzle and breech piece being practically intact. Again, "within a German dug-out which was entered after being bombed, all that could be found in the way of human remains were pieces of flesh, hair and brain plastered on the dug-out wall, while pieces of bone with thoracic and abdominal contents were strewn about the floor." Many instances could be quoted of the disruptive effect of high explosive at close quarters. The chief effect of the *Minenwerfer* and the hand grenade was due to this disruptive effect, and not to their fragmentation.

At a slightly greater distance this concussion effect was seen also in such injuries as fracture of the base of the skull, and all that train of nervous affections summed up under the head of shell shock.

But that missile fragments soon lose velocity is sufficiently demonstrated by the fact that the steel helmet, and in some cases body armour, were found to be an efficient protection against their impact, whereas no protection worn upon the body was found capable of stopping a rifle bullet.

The contrast between the rifle or machine gun bullet and the shrapnel bullet or fragment of shell, bomb or grenade may be summarized as follows:—

Rifle or machine gun bullet.	*Shrapnel bullet or fragment of shell, etc.*
1. Has a fixed weight and shape.	1. Variable in both these particulars.
2. Has a high initial velocity which it loses slowly.	2. Has a lower initial velocity and rapidly loses it.
3. Is purposive in action and depends for its effects upon velocity of impact.	3. Is haphazard in action and depends for effect less upon velocity than upon size and weight.
4. Has great power of penetration and infrequently lodges in the body.	4. Has small power of penetration and often lodges in the body.
5. Does not tend to carry clothing into the wound.	5. Frequently carries clothing into the wound.
6. Explosive exits at short ranges almost invariable.	6. Explosive exits rare.

7. Except when inflicted by machine gun bullets, or when several parts of the body are traversed by the same bullet, multiple wounds are not common.	7. Multiple wounds very common.
	8. The effect of the explosive itself is at least as destructive as the fragmentation.

As regards mode of action, therefore, the rifle or machine gun bullet presents a strong contrast to the shrapnel bullet, and to fragments of shells, bombs and hand and rifle grenades.

CHAPTER II.

RESULTS OF PROJECTILE ACTION.

RIFLE and machine gun missiles have been shown to differ so markedly in their flight and general ballistic behaviour from ricochet bullets, shrapnel bullets, shell, bomb and grenade fragments that it might be fairly expected that there would be a corresponding and recognizable difference in the wounds inflicted. Unfortunately this is not always the case. Characteristic members of each group are to be distinguished, especially where the entry wound in the skin can be seen. It is possible no doubt to lay too much stress upon the shape and size of the entry, but nevertheless this aperture, in most cases, gives the most reliable information as to the nature of the missile. Whatever size of track a missile may cut in the body, its point of first contact with the body is bound to be influenced by its shape, size and velocity. But in the case of gutter and perforating wounds there must always remain a large number in which it is impossible to say whether they were inflicted by shell or bullet. In this question, the patient himself is of no help whatever. Apart from the fact that his attention is usually distracted so that he may not even realize that he is wounded at all, the overwhelming noises of the battlefield make it often very difficult to judge of the direction and range of a gun shot. Bearing these considerations and limitations in mind, it may yet be possible to recognize and describe types of wound entry, track and exit, which are roughly characteristic of the two types of missile which inflict them.

In this connection it should be remembered that it is not only on the battlefield that wounds may be studied. In the case of ricochet, shell and fragment wounds the evidence must be mainly from this source, but in the case of rifle and machine gun wounds there are two other categories of information, namely, the reports of big game shots and experimental shooting, either at human cadavera or those of animals, or even at indifferent substances such as soap, wood, or clay. Much has been learnt from both sources which is of value in solving the problems of gunshot wounds on the battlefield.

Lastly, attention must be directed to a train of results which follow upon the mere detonation of a high explosive, results ranging from complete disintegration of the body to minor

injuries due either to its being carried away by the blast of the explosion, or to burns or secondary missiles. These effects will be considered in dealing with shell and fragment wounds.

Experiences of Big Game Shooting.

As far as wounding power and stopping power are concerned, the evidence of the big-game shot is of great value, if it is always kept in mind that his ideal is not the same as that of the soldier. His ideal is to kill outright and kill cleanly without wounding or causing unnecessary suffering. The soldier's ideal may perhaps be stated to be to kill cleanly, if he must, but he has also to consider wounding as a means of " breaking down the armed resistance of the enemy," and he hopes to find means of doing this " without causing unnecessary suffering."

There is a very large body of controversial literature on the subject of what are the best weapons for big-game shooting. Major Whelan, in his book on the American Rifle, has a chapter on killing power in which a brief summary is given of this controversy. He says " first we had the big and small bore discussion, then the high and low velocity discussion ; next we were treated to a dissertation on energy and footpounds, and to-day it is all explosive effect. What to look for in a big game cartridge is, (1) one which will cause the least suffering by killing as instantly as possible ; (2) one that is accurate ; (3) one which has a flat trajectory, that is, velocity."

Sir Samuel Baker's favourite weapon for all game except buffalo and elephant, was a ·577 double-barrelled rifle, carrying a solid lead bullet of 648 grains, and a charge of 6 drachms of black powder. He condemned strongly the light hollow pointed express bullet. He said the most killing bullet was the largest soft lead bullet which could be fired from the shoulder Light bullets may be stopped by heavy bones and broken up. With black powder, the velocity varied from 1,300 to 1,500 feet per second. All soft lead bullets expand on impact to about double their diameter.

Upon the advent of smokeless powder and small calibre rifles gunmakers turned out soft-nosed bullets. Even then the heavier (220 grains) were found to be better than the lighter ones (160—170 grains). But Major Whelan has never obtained the same large proportion of clean kills with small bores as with heavy black powder rifles. A few failures with small bores on large game led to the manufacture of the ·35 Winchester with 250 grain bullet, and of the ·405 Winchester with 300 grain bullet, and these proved much more satisfactory.

But there are other things to consider besides killing power, such as absence of smoke, light recoil, superior accuracy and high velocity. These fully make up for some loss of stopping power. When small-bore rifles were made a little larger and the bullets heavier, the ideal began to be reached.

About 1906, very high velocity (2,700 feet per second) rifles began to appear. It was feared that they would perforate cleanly, but it was found that they had an explosive effect on animal tissues. They "seemed to spin around on their points." They had, moreover, the undesirable quality of glancing, especially the lighter ones (150 grains), on striking bone. Improvements were made by giving soft noses to these bullets, but they were still liable to break up on a hard bone, even if they were no longer deflected. A ·30 calibre expanding pointed bullet of 170 grains, with muzzle velocity of 2,700 foot seconds, is certainly a most killing and effective charge for all game found in North America. For the heavier African animals the standard weapon is a ·450 or ·465 rifle with a 450 grain jacketted bullet with muzzle velocity of 2,000 to 2,200 foot seconds.

Extremely small bores with high (3,000 to 3,300 foot seconds) velocity are not recommended by Major Whelan. They wound and do not kill, and have little penetrative power.

The following remarks by a small arms expert is an attempt to put into the formal symbols of physics the problem which confronts the big game shot. He says, "It is obviously impossible to reduce wounding power to a strict formula. But still, to think clearly about it, some numbers are necessary and the question is, what formula is useful? Sir Samuel Baker, in his 1891 book 'Wild Beasts,' is very emphatic about the necessity of a large heavy bullet with enough drive to get right into the beast, and enough area *not* to come out. The use of high velocity is to pierce the beast's 'armour,' and there you want the formula for punching a hole, viz., energy per linear inch of circumference. You then have the statements :—

> "(1) The bullet must have sufficient energy per inch of circumference to penetrate the surface skin, and this is $\frac{W.V^2}{D}$ (where W is weight of shot, V is its velocity in foot seconds and D its diameter in inches) and it must be greater than some definite amount varying with the size of the animal. To break bone energy only is wanted, and this is $W.V^2$. It must be different for every animal.

"(2) When the bullet is 'in,' its momentum multiplied by the length of the cut seems to decide the gravity of the wound and this is W.V.D. where the weight, velocity and calibre of the shot are all equally involved.

"A man is roughly one-tenth horse weight and one-hundredth elephant weight, or approximately as $1^2 : 3^2 : 9^2$, and perhaps W.V.D. should vary as 1 : 3 : 9 for the three animals."

From the literature of big game shooting then it is possible to gather the following conclusions—

(1) In the old days of black powder, soft lead bullets and low velocities, a heavy weight of lead was required for killing purposes, to make up for low velocity.

(2) Higher velocities (in addition to other advantages due to smokeless powder) permitted the use of a smaller bore and a lighter bullet. But there was a distinct limit to the possibility of substituting the velocity factor for the weight factor.

(3) The jacketed bullet had the decided disadvantage of breaking up on hard bone.

(4) The pointed bullet, besides breaking up, was extremely liable to deflection on striking bone. Even a rib was able to deflect a light 150-grain pointed bullet. This defect neutralized its otherwise great killing power. Major Whelan says, "It was found they had an explosive effect on tissue, and that they made extremely bad wounds, and had good killing power. On striking *they seemed to spin around on their points*, often penetrating sideways, and the high velocity apparently gave an explosive effect to their blow, so that the tissue for a considerable distance around would be completely blown to a pulp." From this class of evidence the pointed bullet is established as a very destructive missile.

Results of Experimentation.

The second method of estimating the actual possibilities of a small arms projectile is by experimentation. Here the conditions as regards range, explosive charge and manner of impact, can be fixed and known. The object chosen may be a live animal, one recently killed, parts of the human cadaver, or on the other hand substances like wet clay, soap or even wood, which to some extent may furnish inferences as to the effect of the missiles on human tissues. There are, however, some drawbacks to the experimental method which must be borne in mind when drawing conclusions from it. Some of these

may be mentioned:—(1) When firing at full ranges it is difficult to make certain of hitting the exact spot intended. (2) With reduced charges representing full ranges at reduced distances, it is doubtful if the exact combination of translation and rotation is transmitted to the bullet, such as a bullet traversing the full range would possess at the given range. (3) The tissues of live animals differ markedly from those of man. This is especially true of the bones, and, in particular, there is of course no known animal which can furnish a parallel with the skull of man. (4) When the human cadaver is used it has usually undergone preparation by means of some hardening preservative, and its relative content of water (a most important constituent from the point of view of wounding) must vary considerably from what is normal in life. In fact after *rigor mortis* has come and gone in a muscle it is doubtful if anything like the normal in hardness and humidity can be even approximately restored.

Thus, in the many experimental firings which have been carried out the results have always differed from those observed in actual warfare, and they have usually differed in the direction of an exaggerated estimate of wounding effect. While, therefore, experimental results cannot be altogether relied upon, yet when checked by observation of actual wounds in war they afford an explanation of some of the peculiarities of gunshot injuries and may justify a forecast in the case of a particular missile.

When the small bore bullet (of ·303 or thereabouts) was first introduced, experiments on animal tissues were made by such well-known authorities as Delorme and Chavasse in France, Kocher in Switzerland and Paul Bruns in Germany, all employing "simulated" ranges, and arriving at conclusions which do not differ much from one another. While agreeing as to the severity of injuries produced in bone, these observers were inclined to emphasize the "humanity" of the small bore bullet in the case of soft tissues. Later Demosthen, Von Coler and Schjerning, using full charges at actual ranges, found that explosive effects were not so severe as with simulated ranges, and that as the ranges increased destructive effects were perceptibly less. Their conclusions tended to establish the "humanity" of the small bore bullet on a firmer base than ever. And it may be said, speaking generally, that the actual results in the South African War tended to confirm experimental conclusions. The military objection to a bullet of this kind is its want of stopping power.

The factors which influence wounding or stopping power in a bullet may be mentioned as follows.

Weight and cross section area would seem to be, and indeed are, of high importance. *A priori* it seems reasonable that the heavier and broader based the projectile the more severe the injuries it will produce. But it must be remembered that these two factors are governed almost entirely by ballistic considerations and by the general military value of the bullet, and that their influence on wounding power must be sacrificed to satisfy these requirements.

Velocity is a highly important factor. The kinetic energy of a moving body varies directly as the mass, and directly as the square of the velocity for the same mass. A much greater effect therefore will be produced by increasing the velocity than by increasing the mass. In all the late changes in bullets an increase of velocity has been one of the main objects. The effect indeed of increased velocity in the small bore bullet in enhancing wounding power only fails when " vital " parts (*i.e.*, those necessary to life) are destroyed—velocity here is obviously of less value—and when the resistance offered by the tissues is low. On the other hand, it is immensely increased when the resistance is high. Bone injuries at short ranges with the humane small bore bullet are not only very severe but occur at much longer ranges than with the slower moving larger bores.

The old lead bullet " set up " on striking and so increased its area of impact on the tissues. Bullets with a hard metal envelope have to some extent lost this property, unless they are specially made by exposing the lead core at the point, or some such device. Expanding bullets of this kind are much used in big game shooting, and, as already noted, have also been used against fanatical tribesmen and other determined foes, but are expressly forbidden in European warfare by the Hague Convention.

By a comparatively recent alteration of shape, however, the small bore bullet has been associated with a very important increase in its wounding power. The pointed bullet has a greater muzzle velocity, and a greater power of retaining its velocity than the bullet of the South African War, so that severe effects are produced at longer ranges. Moreover, as has been shown in the previous chapter, owing to its shape its centre of gravity is very far back and consequently its stability is greatly decreased. Unless the axis of the bullet corresponds accurately with the curve of the trajectory, there is also a

tendency for the bullet to rotate about its transverse axis, and so to advance through the tissue " side on " instead of " end on." It has been pointed out that the possibility of this turning in the tissues has been denied, and the destructive effects attributed to other causes. But whatever may be the opinion as to its mode of action the effects of this new-shaped bullet in the war have been so profound that its experimental history demands special consideration.

The pointed bullet was introduced by Germany in 1905, and in 1910 Professor Fessler published the results of experiments made by him at the Bavarian School of Musketry on human and animal bodies at ranges varying from 10 to 1,500 metres. His conclusions may be thus summarized :—

(1) The bullet hardly ever breaks up and therefore cannot be classed as " explosive." The point may be bent on striking hard bone.

(2) The centre of gravity of the bullet lies in the posterior third; hence, after meeting with any resisting object, it almost always turns round a vertical or oblique axis running through its centre of gravity, and apparently nearly always strikes a second object broadside on. The nearer the range the less resistance is required to initiate this movement, and the shorter the distance required to permit a complete change in its position.

(3) The first wound made by the bullet always has a greyish black margin. This discolouration is due to partially consumed cellulose. It may be carried into the tissues to the depth of an inch or more, but is never found in a second wound made by the same bullet, or if the wound has been caused by a ricochet.

(4) The kind of wound produced depends mainly on the position of the bullet when it strikes the object, and to a lesser degree on the range, *i.e.*, the velocity at the time. Explosive effects occur up to 700 metres, but no definite zones can be assigned.

(5) In striking soft tissues " point on " the wound of entry is small, the track larger than the calibre of the bullet, and the walls are raw and lacerated (*gehackt*). Hard and long bones are perforated with the formation of a number of radial fissures and splinters. At close ranges minute splinters predominate. Soft organs (liver and spleen) are ploughed up. Vessels and nerves are destroyed. Wounds of entry in the stomach and bowels are small, wounds of exit larger and permit of the escape of contents.

(6) In striking "broadside on," very slight resistance (*e.g.*, the chest wall, a knapsack or even at near ranges up to 50 metres the abdominal wall) is sufficient to induce this change of position. In the soft tissues the track is very much larger than the calibre, and the walls pulped. The exit wound is large. Wounds of the stomach and bowel are large and allow the escape of the contents. Soft organs, such as liver and spleen, are torn up and pulped. When a bullet in the vertical or cross position (*Querschläger*) strikes a long bone up to ranges of 700 metres, it pulverizes the bone, driving splinters and bone debris into the soft tissues, and forms a cavity (*Trummerhöhle*) filled with pulped tissues as large as a goose's egg. At 1,500 metres a *Querschläger* smashes the bone, producing large fragments, but with less pulping of the tissues than at near ranges. The bullet at this range may remain embedded in the body.

(7) At 400 metres range, compared with the M88 Mannlicher bullet, the "S" bullet produces a smaller track in muscles but the walls are more bruised and lacerated. The area of explosive damage in bones is not greater but the bone is much more pulverized, the pulped cavity beyond the bone is greater, and the zone of destruction extends to a greater depth. At 700 metres the destruction is as great as at 400 metres.

(8) The practical deductions from these experiments as affecting war surgery were:—

(*a*) Very large first field dressings.
(*b*) Abundant supply of means for stopping bleeding.
(*c*) More and better splints.
(*d*) Increase in amputations.
(*e*) Much severe internal hæmorrhage.
(*f*) Escape of stomach and bowel contents in all wounds of hollow viscera.

Fessler's deductions are interesting in the light of recent experience, and have been on the whole justified, but it must be noted that there were many cases in which the German bullet broke up on impact and in which fragments of the casing remained in the wound. Whether this breaking-up was due to a previous ricochet or not cannot be known, but the fact that it occurred is of much surgical importance.

Another series of experiments was performed with a slightly different make of pointed bullet in 1910. In this series the bodies of recently killed sheep and horses were used, the

ranges were "simulated" from 100 to 2,000 yards, and the parts fired at were skiagraphed and carefully dissected. The results may be summarized as follows:—

(1) Entrance wounds were always small and typical.

(2) Explosive exits occurred in 30 per cent. of wounds, and in one third of those the soft parts only were involved. Explosive exits were seen up to 500 yards, but none at 1,500 and 2,000 yards.

(3) The bullet was deformed in 28 per cent., and broken up in 13 per cent.

(4) Lodgment in the tissues occurred in 10 per cent. in ranges over 1,500 yards.

(5) Turning on a transverse axis occurred in 63 per cent. of all wounds, and the bullet was deflected in 13 per cent.

(6) In 17 per cent. the tracks resembled those made by the blunt-tipped bullet. In the remainder they were much more severe with a high degree of laceration of the soft parts.

(7) In bone injury the degree of comminution was high at all ranges and the destruction of cancellous bone was also great.

The general conclusions were that larger exits may be expected with consequently increased tendency to infection; more severe injury to soft parts, in which the viscera will share in a marked degree; and no great enhancement of injury to bone, except perhaps to cancellous bone.

Several other examples of experimental work might be given, but the instances quoted are typical and the inferences drawn from them are in the main similar.

As regards the use of indifferent materials, there is not much to be learnt from a surgeon's point of view. An illustration from Colonel Lagarde's book on gunshot wounds shows chiefly the power of penetration of the Springfield bullet weighing 150 grains. It penetrated 28¼ inches into thoroughly seasoned oak across the grain at a range of 50 feet It also shows the somewhat spiral course of the bullet in its passage.

Of even greater interest are the experiments carried out by Sir Victor Horsley, who used wet modelling clay and filled the cavity caused by the bullet with plaster of Paris, and so obtained a cast of the excavation. He states that the so-called "explosive effect" is directly proportional to the sectional

area of the bullet, to its velocity, and to the amount of water present in the tissues traversed, and that the forces of disruption act at an indeterminable angle to the axis of the bullet's flight. He regards the rotatory movement of the bullet as the more important " from the pathological point of view." He found that disruptive tears in the clay often took " a spiral direction antero-posteriorly." As regards the pointed bullet, he says that the " apex of a bullet has no bearing on the immediate question of the amount of destruction," and that turning only occurs when a bullet has completed some of its course in the body and has lost velocity, and concludes that turning over is not to be credited with doing much harm, the real cause of the destruction of tissue being the high velocity and rapid spin.

Conclusions, however, drawn from experiment with indifferent substances are of little value where the question of destruction in the human body is concerned. They are of more value in indicating the behaviour of a bullet in its flight. The human body is in no sense a mass of homogeneous tissue enclosed in an elastic envelope, but a complex of structures of varying fluidity and hardness.

Effects of Explosion.

Before discussing the actual battle lesions, something must be said of a series of phenomena peculiar to wounds by artillery projectiles, bombs and grenades, where the lesions observed are the result of the actual explosion itself, and not merely of the missiles set in motion by it.

(*a*) *Disintegration.*—The literature of the present war is full of instances of the disruptive effect of high explosives at close quarters. One instance has already been quoted. Hughes and Banks make the following further observations. Disruptive phenomena also occur where there has been absolutely no evidence of tissue penetration. They have been observed to follow most frequently the explosion of large trench mortar projectiles. The effect is local and is effectually guarded against by " traverses " in trenches. If there are no traverses, however, the force of the explosion can be unpleasantly felt at a distance of 200 yards. Similar results are observed when hand bombs and grenades explode in confined spaces. A Mills bomb bursting in the open does not make its explosive force felt at a much greater distance than 30 yards, but when burst in a trench or dug-out its effects are formidable. As an instance of the effect of a trench mortar projectile, a case is given where one exploded

near a signal dug-out in which two signallers were working. Nothing more was seen of either of these men except one of their lower extremities which was hanging in the German wire about 150 yards away. It had been disarticulated at the hip joint. The number of men who have completely disappeared during the war, and whose deaths have had to be presumed, suggests that these disruptive effects are by no means rare.

(*b*) *Death without Disintegration.*—But death may occur from the effects of high explosive without the disruption mentioned above; in fact there is sometimes no actual sign of external injury at all, and bodies are found in the attitudes of life, having evidently been killed instantaneously. Sir Anthony Bowlby calls attention to this fact in his Bradshaw lecture on "Wounds in War." He says, "The expansion of the gases is alone sufficient to kill, and in the only case in my experience in which an autopsy has been made, the brain was the seat of very numerous petechial hæmorrhages." That the cause of death in these cases is due to some violent impression upon vital tissues is clear, but the exact mechanism of action, the actual tissues upon which the stress falls, have been the subject of some discussion. M. Arnoux, a French civil engineer, writing in *Le Journal* of July 6th, 1915, suggests that the high atmospheric pressure of the explosion wave produces the same effect as the so-called *caisson* disease, an absorption of gases into the blood and their subsequent rapid liberation, producing air embolism. Surgeon-General W. F. Stevenson, however, puts his finger on the weak spot in this theory. The compression wave has not time to cause gas absorption, always a slow process.

Dr. Lewis Thomas, from his experiences of an explosion of nitro-glycerine, suggests that death from explosion is due to the "sudden snatching away of the atmospheric pressure in and around the bodies by the voracious vacuum suddenly produced outside." He tells of a surgeon in a German dug-out, near which a huge shell burst, who "had a dreadful indescribable but momentary sensation, which was immediately followed by a rush of dust-laden air filling the dug-out." His survival was due to the presence of an air inlet into the dug-out The suggestion is that a temporary vacuum is produced with release of pressure from and perhaps escape of the fluids and gases inside the body.

A series of experiments, the results of which have not been published, was conducted in Rouen in 1917, by Dr. George Crile, of America. He subjected animals, such as rabbits and

dogs, to the effects of explosions in a confined space, and his post-mortem examinations seemed to demonstrate that the main stress of the explosion did not fall exclusively upon the nervous structures, but fell also in a marked degree upon the lungs. These organs were the seat of massive hæmorrhages in which in many cases more than half the lung was involved. Other experimenters, such as Mairet and Durante, lay stress upon the pathological changes in the brain and spinal cord. They found minute scattered hæmorrhages due to rupture of small vessels. Blood is found in the lymphatic sheaths, and the vessels most commonly ruptured are those which have the least support by solid tissue.

F. W. Mott, commenting upon the post-mortem appearances in two cases which died some hours after exposure to shell explosions, says that in the cells there was a general, though not as a rule marked, chromatolytic change indicative of a lack of kinetoplasm in the neurones, the cells of Purkinje of the cerebellum showing especially a partial or complete loss of basophil substance; that there were no punctate hæmorrhages of the white matter, but signs of arteriocapillary anæmia and venous congestion, and that two hypotheses have been put forward to explain organic lesions by commotion; the one, compression of the gas and atmosphere, so that the cranium and spine are struck as it were by a solid body, and the vibration is transmitted through the bony structures to the cerebro-spinal fluid and thence to the brain and spinal cord, causing a molecular disturbance of the delicate colloidal structures of the neurones, particularly those of the nuclei in the floor of the fourth ventricle where the fluid is most abundant and where it acts as a water cushion upon which the vital cardio-respiratory centres rest; and the other, compression followed by a corresponding decompression, causing the liberation of bubbles of gas in the blood and tissues leading to embolism. It has already been suggested that the time of exposure is too short for the development of these physical changes.

Lastly, it may be added that death is sometimes due to burns caused by the flame of the explosion.

(*c*) *Shell Shock.*—Besides injury which is immediately or remotely lethal, the organism may present as a result of exposure to continuous shell fire that train of nervous symptoms, largely psychical, but on the borderland between psychical and organic, which has come to be known as shell shock. It has been observed that the vast majority of non-fatal cases

of shell shock are more emotional than commotional, and occur especially in subjects of an inborn neurotic or neuropathic temperament, but that the two conditions may be associated. That they are by no means interdependent, however, is shown by the fact that cases showing unmistakable signs of slight localized organic lesions may entirely recover without developing any traumatic neuroses. In the opinion of one German author, micro-structural changes occur, including meningeal oedema, microscopical hæmorrhages, transitory paralyses of vessel walls and contusion of nuclei and centres. These lesions may at first give rise to some symptoms of organic disease; later, they are manifested by functional physical and psychical symptoms. There is, then, some difference of opinion among neurologists as to whether actual tissue changes are in all cases antecedent to the development of shell shock. But whether physical or psychical, the condition is a well-recognized result of explosion.

(*d*) *Other Injuries.*—It is naturally difficult in some cases to distinguish injuries due to the actual shock of explosion from those due to the body being hurled against other objects or buried under earth or ruined buildings. Fractures and ruptures of viscera are often seen. Burns varying in degree and extent may occur. Hughes and Banks quote the case of an officer who was found five days after exposure to an explosion to be suffering from fracture of the base of the skull. A case is known where both ossa calcis were fractured But besides the extensive peppering of the face and hands with small wounds caused by earthy particles, injury to the eye is often produced by the same agency; and Dr. Jameson Evans has drawn attention to the fact that while impairment of sight, contraction of the visual fields, photophobia and blepharospasm, may be seen without evidence of gross injury and may therefore be classed as traumatic neuroses, there is a number of cases where injury at the macula, hæmorrhages in the globe, ruptures of the choroid and optic atrophy may be found without any superficial sign of injury whatever—cases which are probably concussion effects.

As might be expected, the auditory apparatus sometimes shows the effects of concussion. Dr. J. Gordon Wilson finds that the chief symptoms are deafness and disturbance of equilibrium, which may occur with or without rupture of the membrana tympani. He is also of opinion that high explosives may cause a definite injury to the central connections of the ear. The hearing may recover quickly, but the disturbance

of equilibrium may persist for some time. Associated with these auditory symptoms there may be headache, bad memory for heard words, and a limitation of the field of vision.

Varieties of Wounds.

The varieties of wounds met with in warfare may be considered briefly from the point of view of their anatomical situation and the actual injury to the tissues involved. It is convenient to divide war wounds for descriptive purposes into four main categories :—

(1) *Contusions.*—A typical wound may be defined as consisting of entry, track and exit ; the contusion may be said to be track without entry or exit. It is usually due to large shell fragments or whole shells, striking at an angle and when moving slowly. The elastic skin escapes, but muscles and fasciae are crushed and pulped, viscera are ruptured and bones bruised or broken. This kind of injury was formerly attributed to the wind of a shell. Cases have been recorded where it was due to a spent rifle bullet, and Sir Frederick Treves mentions one in his experiences of the South African War. The damage to tissues of the softer kind is in no way dissimilar to that seen in civil accidents of the same kind.

(2) *Penetrations*, which are called by Delorme " cul-de-sac " wounds, have entry and track without exit. Impaction of a missile in the body predicates relatively low velocity. Consequently, unless of large size, these missiles cause less damage to the tissues beyond the track than those moving more rapidly. This form of wound is the characteristic small shell fragment wound. It is very frequently multiple, and is the seat of impaction of foreign bodies, and therefore usually septic. The skin entry is commonly somewhat smaller than the fragment which causes it, but a good deal depends upon situation. If the wound is across the natural lines of elastic tension of the skin, the entry may be widely gaping. The muscles and fasciae are pulped and destroyed in the actual track of the missile, but beyond the actual track there may not be much damage unless a large shell fragment has caused great bruising, and then there may be widespread necrosis. The hollow viscera, though perforated, do not show the extensive tears seen with high velocity projectiles. Bone is contused, or if comminuted the fragments are large and not much displaced.

(3) *Perforations*, called by Delorme " seton " wounds, show entry, track and exit. Typically this is the characteristic

wound of the rifle bullet. The entry of the latter is usually a punched-out hole, with complete loss of skin, which is probably distributed in a particulate form along the first inch or two of the track. Oblique impacts result in flame-shaped entries, and impacts in loose skin sometimes take the form of slits. The track in these wounds always shows a high degree of disorganization of tissue. It is larger than the calibre of the bullet and lined with devitalized tissue mixed with blood clot. Solid organs are pulped and often show radiating fissures. Hollow organs frequently show tearing and destruction of a higher degree than the size of the missile can account for. Bone is usually broken into small fragments, some of which may be forced through the skin. The exit may be of the same small round, punched-out kind as the entry. More often it is a good deal larger and lacerated. Sometimes it is of great size and shows shreds of muscle and of tendons and fasciæ bound together by blood clot and protruding from an irregular crateriform opening in the skin. The gutter wound is an example of a perforation which lies near the surface of the body. In certain parts of the body, *e.g.*, the head and abdomen, it may be more dangerous than it looks at first sight. To what extent perforations by missiles of very high velocity cause damage to parts remote from their track has been much discussed and will be referred to again later, but the train of motor and sensory symptoms shown in limbs hit by high velocity missiles, and sometimes called local shock, points to radiated effects on peripheral nerves. The lowering of sensibility to pain in these cases is particularly marked, and immediate amputation at the seat of injury has been performed painlessly without an anæsthetic on limbs in this condition of local shock.

(4) *Severe Lacerated and Contused Wounds* are usually due to large shell fragments. These wounds are of the same nature as some machinery accidents in civil life. The extremities are often completely carried away, avulsion at the shoulder and hip being seen. The abdominal wall has been cut away, the greater part of the buttocks torn away, the lung herniated through an immense gaping wound of the chest wall, and so on. These wounds are usually fatal on the battlefield.

Wounds of various Tissues.

A detailed description of the damage to individual tissues would require much space, and in any case the nature of these injuries is far better studied in the drawings and specimens

shown in the museum of the Royal College of Surgeons. Only a concise description will, therefore, be attempted.

It should be borne in mind that a war missile which has sufficient velocity to penetrate the skin will, unless it is very minute, generally destroy completely any soft parts with which it comes in contact. There is very seldom any pushing aside of tissues, except in the case of spent shrapnel bullets. The only debate is as to the extent of injury beyond the actual track. From what has already been said, it would appear that radiated injury is largely dependent upon the velocity of the missile. In the case of bone, all degrees of injury may be seen, from contusion to extreme comminution, but the same fact holds good, that the part struck by the missile is pulverized and destroyed. Radiated injury in the case of compact bone is seen in the comminution and fissuring which extend from the site of impact.

Skin and Subcutaneous Tissues.—Some allusion has already been made to skin wounds. Of the entry it may be said that so closely is it associated with the velocity and shape of the missile that the identity of the latter may often be inferred from a careful examination of the entry. Thus the higher velocities usually cause a completely punched-out hole with loss of the skin. A shrapnel bullet causes a large contused hole with gaping margins. Shell fragments sometimes cause the same kind of wound, but often cut and tear with complete destruction of the skin. When fragments are very minute they may penetrate the skin by holes so small as to be hard to find, and yet do much damage to deeper parts. If the skin is well supported, the wound of entry tends to be somewhat larger, but if lax the aperture is often a slit.

Exits are much more variable than entries, and as regards size and shape are even more dependent upon the velocity of the missile. Even when soft parts only are hit at short range by a rifle bullet, there may be a very large and ragged exit, but when bone is hit and comminuted under the same conditions the exit is nearly always of the so-called " explosive " type. With the old blunt-nosed bullet the exit was often as small as the entry and difficult to distinguish from it. But the pointed bullet causes less of these clean " seton " wounds. The tendency to turn in the tissues is plainly seen in certain multiple wounds where the bullet traverses first one part of the body and then another. Exits by shell fragments and shrapnel bullets are exceedingly irregular and are nearly always large and lacerated, whether bone has been hit or not.

Subcutaneous tissues often undergo much more pulping and laceration than the size of the entry and exit would lead one to imagine.

Muscles and Fasciæ.—These tissues form from two-fifths to three-sevenths of the body weight, and as might be expected are more affected by injury in most parts of the body than any other tissue. Some observers also think that the fact of their being enclosed in sheaths makes them more obnoxious to the divulsive action of high velocity missiles. It is rare to find a single break in their continuity after gunshot injury. They are generally shattered and crushed.

Bone, Compact and Cancellous.—In the case of the old blunt-nosed small-bore bullet, it was learnt from the South African War and other campaigns that cancellous bone was often at long ranges traversed by a clean cylindrical track, the damage amounting to no more than might be seen in soft parts, and that compact bone showed a series of fractures which could be represented almost diagrammatically as the "butterfly," the "wedge," the "oblique" and the like. The degree of comminution depended upon the velocity, *i.e.*, the range of the bullet, and it must be always kept in mind that in South Africa the range was rarely less than half a mile and was very often much more, whilst in the war of 1914–18 the great majority of the wounds were inflicted at quite short ranges. With the pointed bullet, as was foretold by Fessler, the degree of comminution is much higher, but the general lines of fracture are much the same as with the blunt-nosed bullet. Bone is reduced to bone-dust at the point of impact, and from that point fissures radiate upwards and downwards. Cancellous bone, however, suffers a much graver amount of damage with the pointed bullet, and it is rarely that clean tunnelling is observed. More often the whole mass is broken up into large cancellous fragments.

Many of the bone injuries, however, were due to shell fragments, and consequently many different forms of bone fracture were seen, so that it would be impossible to reduce them all to type. Impaction of fragments in cancellous bone was very frequent, or portions of the latter might be carried away. In compact bone, irregular fractures were seen without a high degree of comminution, though the fragments might be large and numerous.

Vessels and Nerves.—With the round leaden shrapnel bullet these structures were frequently pushed aside and though contused were not destroyed. With the old blunt-

nosed bullet they were sometimes divided partially or completely, and sometimes perforated, and it was often remarked that a bullet would perforate a vessel or nerve of smaller calibre than itself. In the case of nerves, the mere passage of such a bullet in their vicinity caused a degree of concussion which sometimes lowered and often destroyed their physiological continuity and conductivity.

The pointed bullet seemed to be more destructive to vessels. A large number of arterio-venous communications was certainly seen, but they were due quite as often to shell fragments as to bullets, and the probability is that in most cases the pointed bullet completely severed the vessels in the limbs with which it came in contact.

Several instances of vascular wounding are to be seen in the War Office collection at the Royal College of Surgeons, some by fragments of minimal size, some by larger pieces, and some by rifle bullets. Sometimes the middle and inner coats are ruptured and the outer is left intact, as the result of contusion. But when the vessel is actually perforated there is no evidence of any hydrodynamic effect upon the vessel wall, a fact which Professor Shattock attributes to the great resistance which the arterial wall presents to internal pressure, and to the continuity of the fluid contents with those within the neighbouring arteries or veins, whereby ready displacement would take place.

Such surgical curiosities as the escape of a bullet into the circulation, and its impaction in a vessel, or the presence of a shrapnel ball in one of the cavities of the heart, were occasionally seen.

The injuries of the nervous and vascular systems and of the thoracic and abdominal viscera are fully described in the chapters dealing with these subjects.

*The Radiating Effects of Missiles.**

The extent to which the tissues may be injured beyond the actual track of the missile has been the subject of much difference of opinion, some writers believing that there is no destruction beyond the tissues which are exposed to the passage of the missile, while the majority believe that the force of the injury always radiates into the neighbouring parts for some distance. It is practically certain that neither of these views meets the case, and that the immense variety, both in the

* This note on the radiating effect of missiles is by the editors.

missiles and their velocity as well as in the nature of the various tissues composing the human body, results in very varying physical conditions as far as wounds are concerned.

In the first place, much must necessarily depend on the size of the missile, for a big jagged fragment of metal tearing its way amongst the large muscles of the thigh or back must contuse the tissues far and wide, and probably tear many small vessels at a distance. Again, a wedge-shaped missile travelling, as may the present rifle bullet, at more than 2,000 feet a second and rotating at great speed, is much more likely to affect the tissues around its track than the old cylindrical bullet of the South African War, travelling and rotating slowly at the end of a long flight; and it does not follow that, because one observer in examining a particular wound fails to confirm the observations of another observer on another wound, therefore the observations of the latter are incorrect. Thus, from the point of view of microscopical examination, McNee and Stokes have put on record that the damage in some cases is certainly not confined to the track of the missile, for they found at varying distances from the wound rents tearing across several bundles of muscular fibres, the ends of the muscle showing necrosis, and the rent itself filled up with blood clot. Bashford, however, does not think that these remote and other far-reaching effects are universal, and says that in injury to the muscle the margin of the injured part is as sharp as if it had been cut with a knife.

It is probable that the observations of both these pathologists are correct, and that the question is one to be decided rather by clinical experience than by anything else. While, therefore, it is not to be denied that in a large number of all wounds the effects of the injury are limited to the tissues immediately surrounding the track of the missile, it is of the utmost practical importance to realize that there are many exceptions to this, and that these should be kept in mind by the surgeon. The following examples will make the matter more clear.

In the South African War complete and permanent paraplegia was seen to follow a cleanly perforating bullet wound of the body of the first lumbar vertebra in which the spinal canal was not opened at all. In the first few months of the war of 1914–18 a man died completely paralysed after a wound by a bullet which had just touched the spine of the fifth cervical vertebra, the spinal canal not being opened and the meninges being intact. Section of the cord showed

hæmorrhage into the grey matter and disintegration of the anterior horn. During the war many other similar cases were observed.

It is well recognized that a tangential or gutter fracture may be the cause of serious brain injury, but it is not always appreciated that the brain may be injured without any fracture of the skull. The following three cases of this kind were observed by Major Adrian Stokes during the year 1915 :—

(1) Bullet wound in occipital region causing coma and death. The post-mortem examination showed that there was no fissure or fracture of the skull and no hæmorrhage between the dura mater and the bone, but the occipital lobe was pulped.

(2) Wound of mastoid region and death from coma. After death it was found that the missile had passed through the muscles attached to the mastoid, but had not even divided the pericranium. There was no fracture and no bleeding between the bone and the dura mater, but the cerebellum was smashed.

(3) Wound of frontal region and death in a few hours. No fracture of the skull found after death, but the superior longitudinal sinus was torn and there had been extensive hæmorrhage.

It will be found in the chapter on injuries of the lung that the effects of a wound could be traced to some distance in the pulmonary tissue and also that missiles which did not penetrate the chest walls occasionally caused a hæmothorax.

A man died soon after admission to a casualty clearing station after a wound of the chest wall. After death it was found that he had a long gutter wound exposing, but not fracturing, the right ribs and the sternum. There was no hæmorrhage into the mediastinum. The pericardium was greatly distended with blood and a small ragged tear had opened the cavity of the right ventricle near the apex.

The abdominal viscera which were outside the track of a missile were not infrequently injured, and, as soon as operations began to be regularly performed for wounds of the abdomen, it was found that the intestine or its mesentery might be torn without the peritoneum being opened. One of the first cases to be observed was a gutter wound caused by a bullet in the left inguinal region, in which as the peritoneum was not wounded the surgeon did not open the abdominal

cavity. After death a torn coil of bowel and mesentery was found with much hæmorrhage. In a large number of other cases of wounds in the lumbar region where the colon had not been touched by the missile the evidence of serious injury to the bowel was supplied by the subsequent sloughing of the gut in the course of a day or two, and Majors Dunn and Drummond found that in many such cases where the colon had not been wounded by the missile its mucous membrane had been torn.*

The solid viscera were not commonly damaged if they were outside the track of the missile, but stellate cracks of the kidney were seen in some such cases, together with slight hæmaturia, whilst in others where one pole only of the kidney had been wounded Stokes found that the unwounded area might also show evidence of injury at the other pole. The liver also was sometimes fissured superficially at some distance from a wound.

The train of motor and sensory symptoms shown in limbs hit by high velocity missiles and sometimes called "local shock" points to radiating effects on the peripheral nerves, and it should be noted that the numbness and lowering of sensibility to pain which immediately follows some extensive injuries may be utilized by the surgeon for the performance of operations without the need of anæsthetics. In other cases the occurrence of thrombosis in large unwounded veins, or even in arteries, indicated a damage to their coats beyond that which the surgeon could perceive when he examined the wound.

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CHAPTER III.

WOUND SHOCK IN FRONT LINE AREAS.

THERE are many different clinical conditions included under the term "shock." In order to avoid misunderstanding it is advisable to adopt a more precise terminology, and not to speak of "shock" alone without further qualification, such as "surgical shock," "concussion shock," "shell shock," "toxic shock," or "traumatic shock." The word "shock," originally of Dutch origin, may have come to us as *le choc* of the French, and was originally employed to convey the idea of surgical shock. When, however, these other varieties of shock came to be discussed, confusion immediately arose. In describing the form of shock met with in the wounded, the expressions "surgical shock" or "traumatic shock" have been used, but a clearer term has been suggested, namely "wound shock." This is a simple descriptive term and one which recalls to the mind all the associated ætiological factors. As will be shown subsequently the further subdivision of the condition into primary and secondary wound shock still further simplifies the description and conception of the condition.

Other terms that have been suggested are "oligæmia" of various American writers; this is intended to signify the reduction of the blood volume in effective circulation. Professor W. B. Cannon, in discussing the need for exact terminology in writing on "shock," makes a strong plea for the re-introduction of the Hippocratic term "exæmia" (drained of blood) and claims that the word is at once pathologically accurate as well as descriptive of this classical condition. Such elaborate terms, however, while perhaps of use to laboratory workers and scientific investigators, do not have the same practical application to the military surgeon and his orderlies as the simpler term "wound shock." This name has since been adopted by Professor Bayliss and subsequent writers on the subject.

The condition is that which may be seen in a wounded man, where as the result of tissue laceration, exposure to fatigue, pain, cold, sepsis and hæmorrhage of varying degrees of severity, the systemic blood pressure falls, capillary concentration with stasis of the blood occurs and the circulation gradually fails. This results in a fall in body temperature,

failure of the process of intracellular oxygenation, and finally ends in death. The clinical conditions resulting merely from exposure to the stress of modern warfare, where psychical and mental symptoms alone occur, do not fall into the class of case under discussion.

During the early months of the war the whole energies of the forward units of the medical service were, from the mobile nature of the campaign, directed for the most part towards the rapid evacuation of the wounded. By the winter of 1914–1915, however, as trench warfare developed, it became possible to establish more stationary units where fuller and more detailed attention could be directed to the treatment of those wounded who were suffering from collapse and " shock." The advantages of special treatment were demonstrated in the winter of 1914–1915, by those hospitals where special wards were set apart for dealing with such cases.* " Moribund " patients were put into warm beds, given subcutaneous and rectal saline injections, and many lives were undoubtedly saved.

In 1915 the modern technique of war surgery was gradually developed and the surgical organizations in front line and clearing station zones were constantly improved. As regards " shock," the most important change in treatment was the recognition of the extreme importance of continuous, early and rapid evacuation of all wounded men from the battle zone to the front line operating centres. Many patients now came under more elaborate treatment than had previously been possible in the field ambulances, and benefited accordingly.

In August 1916, Professor Bayliss published an important paper on the treatment of low blood pressure conditions, which prepared the way for the introduction of new methods of treatment of wound shock in the following year. By the end of this year many clinical notes and blood pressure records had been accumulated, and important clinical observations on the concentration of the blood had also been made. In the treatment of the Somme casualties in the summer and autumn of 1916 intravenous infusion of normal saline was carried out on a large scale, but it was found most disappointing.

Early in 1917 the great need for further knowledge of the pathology of " shock " was felt more deeply than ever, and the inadequacy of the prevailing methods of treatment was widely recognized. In February of this year the Medical Research Committee published its first Memorandum on the subject, and in August formed in London the special investigation

* As for example at No. 8 Casualty Clearing Station at Bailleul.

committee which, by its close co-operation with the army medical authorities and clinical workers of the medical service in France, performed much useful work in dealing with the problems of the investigation and treatment of wound shock.

In the summer of 1917 the army medical authorities arranged for the formation of special investigation centres in different parts of the forward areas in France.* In the First Army Centre from June till October many important observations were made and much material was accumulated and subsequently published by the Medical Research Committee in a series of six papers, December 1917. In the First Army also a series of observation stations was organized, in which a study of the pre-wound condition of soldiers was made, records of blood pressures and symptoms at the moment of wounding were taken, and further notes collected during the man's evacuation down the line until he arrived at the operating centre. Here clinical observations before, during and after operation were recorded, together with clinico-pathological investigations on the alkaline reserve of the blood, the state of the blood concentration, sugar content and so on. From these studies of the origin or "initiation" of wound shock, recognition was made of the primary and secondary varieties, a conception which has proved of value in discussing and deciding the lines of treatment to be adopted.

As a result of these investigations an energetic "anti-shock" campaign was started in the summer of 1917. The army medical authorities immediately published circulars to all front line units, describing the new views on the pathology of the condition and conveying practical suggestions for the treatment and prevention of wound shock. General interest was rapidly aroused and before long in every regimental aid post and advanced dressing station measures were adopted which resulted in the greatly improved condition of the wounded.

This year also saw the introduction of Bayliss' gum-saline solution as well as a further spread of the practice of blood transfusion in the treatment of wound shock.

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* In June 1917, a centre was organized at Béthune at No. 33 Casualty Clearing Station by the D.M.S. of the First Army and his consulting surgeon, and, in July, Professor Crile, U.S.A., co-operated at Rémy Siding with the consulting surgeon of the Second Army and the Staffs of Nos. 10 and 17 Casualty Clearing Stations. In September 1917, in the Third Army, the D.M.S. and his consulting surgeons formed an army shock committee for the encouragement of research and for the circulation of the latest results of investigation.

During the early months of 1918 the American troops arrived in increasing numbers. The Army Medical Service placed the results of the shock research at their disposal, and many of the newer methods of treatment were adopted.* With the resumption of active warfare in the spring and the subsequent movements of hospitals so that the wounded once more had to be transported long distances, the increase in the number of shock cases again accentuated the problems of the best methods of treatment. Large resuscitation wards were prepared in the clearing stations, where teams of specially trained medical officers, sisters and orderlies were organized and available, and in such wards the treatment of wound shock was carried out for the rest of the war, as for the most part elaborate means of treatment were not possible in the field ambulances, although simple arrangements were provided for warming patients. Further research in 1918 consisted chiefly in following out ideas suggested by the Béthune centre, namely, measurement of the blood concentration, and observation of its behaviour as the result of treatment.

Finally in 1919 a valuable report was published by the Medical Research Committee on traumatic toxæmia as a factor in shock.

During the two years in which these " shock " investigations were pursued in France, a large number of new observations was collected, as a result of the careful organization and the intensive methods adopted. These are likely to prove of great value not only in enabling the knowledge of wound shock to be placed on a sounder footing, but also in enlarging the views on surgical shock as seen in civilian surgical practice.

The Physiology of the Fighting Soldier.—In order to investigate the factors which might be present before the man was wounded, and which might predispose to wound shock, Captain Cowell spent some time living in the trenches, watching the soldier under different circumstances, and taking blood-pressure observations as often as possible. The average maximum systolic pressure was found to be 110–125 mm. of mercury and the diastolic or minimum 75–80 mm. In the unwounded the variations were those of hypertension, and were generally found in men subjected to stress or excitement.

Perhaps one of the most fascinating subjects in physiology is the study of the reaction of the body to excitement. Of

* In March, under the auspices of the American Red Cross, a conference of leading American and British army surgeons was held in Paris, where shock problems were discussed at great length.

the psychical stimuli which result in extensive physiological processes that of the excitement of battle probably comes first, converting the normal human mechanism into a fighting machine. Cannon and Elliott found that, as the result of excitement in cats, sympathetic stimulation set free adrenalin, which could be detected in the circulation soon after the initial stimulus was applied. The main effects of this circulating adrenalin are to increase the heart-rate, raise the blood pressure, set free glucose from the liver in response to the demand of the muscles for more foodstuff, inhibit the movements of the alimentary canal, and diminish the coagulation time of the blood. The utility of these bodily changes is obvious, enabling the man to do more muscular work, withstand fatigue longer, and in the event of his being wounded hastening hæmostasis. As will be shown later, however, it is possible that the secretion of adrenalin over a prolonged period may be harmful, and that prolonged excitement may prove to be one of the factors in the initiation of wound shock. The observations which have been made on the effects of excitement on soldiers show that a stimulus such as exposure to danger of enemy fire produces a reaction which, as might be expected, varies greatly according to the individual. Intellectual development, temperament, habitual exposure to danger in war or civilian occupation, and fatigue have all a bearing on the physiological reaction as estimated by the sphygmomanometer. The effect of temperament is shown in the following cases.

At 2 a.m. on a dark night in the autumn, records were collected in a battle aid-post situated in a well-known sector of the line (Chart I). The men under observation were all slightly wounded and had just dropped back into the trench after having "gone over the top" on a raid. The artillery and machine-gun fire to which they had been exposed was severe. The men were in civil life farm labourers of particularly phlegmatic temperament.

No. 1.—A slight wound of the face. The man took everything as a matter of course, and sat quiet without speaking. Pulse 76. B.P. 115 mm.

No. 2.—Bullet wound of the hand; some pain. This man was talkative; later sang and showed signs of mild excitement. Pulse 125. B.P. 130.

The other four men had all come in at the double and were panting when first seen. Pulses and respirations slowed quickly on resting.

No. 3.—Slight wound of chin. R. 36. P. 144. B.P. 115.

No. 4.—Perforating bullet wound of arm. This man was rather pale, but was quite cheerful and had not lost blood. Pulse 120. B.P. 120.

No. 5.—Slight bomb wound of the buttock. Pulse 124. B.P. 115.

No. 6.—Slight wound of the face. This man was of less robust physique than the others and looked in a bad way, with a pale face and weak voice. He wanted to lie down, having given in completely. There was no serious wound to account for this. Pulse 112. B.P. 120.

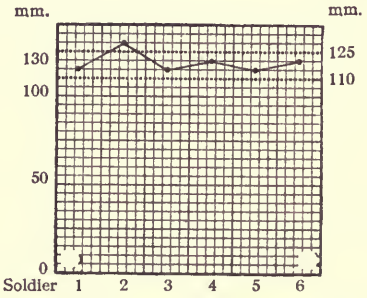

CHART I.—Chart of blood pressure of six phlegmatic soldiers after a trench raid.

Note.—The dotted lines on each chart at 110 and 125 mm. indicate the normal limits of blood pressure.

A few weeks later advantage was taken of the full moon to collect blood pressure records of a garrison of a detached outpost situated in a new part of the line which was somewhat exposed. The men were organized into a series of posts, where they had been on duty for four nights and four days with only brief snatches of sleep in the day-time. The nights were cold, and although the men were well fed, the water ration was only 10–15 oz. per man per diem. The following figures were written down in the order in which the readings were made. When the enemy fire came within a few yards a note was made as shown in Chart II and following table.

The evidence provided by these readings seems to afford clinical support to the experimental observations of Cannon and Elliott already referred to. It will be seen on examining the chart that at the posts where there was special danger the men were found to show the greatest reaction. A large number of blood pressure observations was taken of men

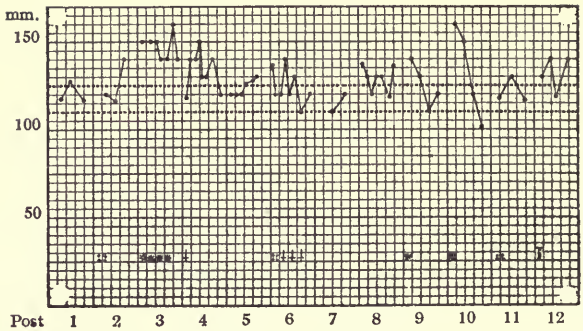

CHART II.—Chart showing blood pressure records under stress :—‡ Machine gun bullets. * Rifle grenades. † Véry lights. § Shell.

Post.	B.P.	Remarks.	Post.	B.P.	Remarks.
1	118–80 126–90 116–80	Quiet.	6	136–85 120–80 120–80 140–80 120–75 130–80 110–60 120–65	Quiet. Several Véry lights.
2	120–80 116–75 140–80	Fairly quiet.	7	110–80e 120–60	(*e*) Two years in the line.
3	150–90 150–90 150–80 140–70 140–70 160–90a 140–90a	In sap leading to enemy's lines. (*a*) Two last men just knocked down.	8	138–80 130–75 120–85 130–90 130–80 124–70f 136–70	Important M.G. position. (*f*) Very cold.
4	118–70 140–90 140–80 150–90b 130–90 130–90 140–90 120–90c	Quiet, but not very far away from 3. (*b*) N.C.O. i/c. (*c*) O.C. on his round.	9	140–90 130–80 110–60 120–90	Slightly active.
5	120–80 120–80 120–90 126–76 128–75 130–90d	Quiet. (*d*) Sergeant.	10	160–90 150–90 120–70 104–70g	Sentries at Coy. Hqrs. (*g*) Two years in the line.
			11	118–80 130–90 116–60	Stretcher bearers and guide.
			12	130–90 140–90 118–80 140–90	Patrol party after 1½ hours' march in the trenches.

of all ages and regiments in different parts of the forward areas in quiet times. The average was found to be 125–110, or even lower occasionally. For the sake of comparison the blood pressures of twelve groups of men were taken at random and plotted in the following chart.

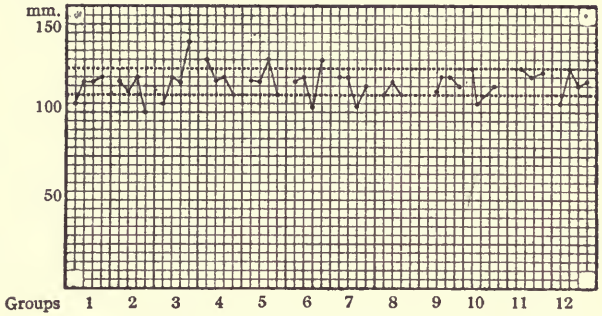

CHART III.—Chart showing blood pressure of soldiers at rest, in groups picked at random.

Blood Pressure in the Wounded.—Observations were made in the line, as soon as possible after the wound had been inflicted. In the trivial wounds, while transient physical disturbances sometimes resulted and the man became momentarily faint, the hypotension did not exist long enough to be measured. On the other hand, in slight wounds the pressure was more often raised. For example, a strong healthy young gunner was slightly wounded with a few shell splinters. He walked to the dressing station and was seen half an hour later. His face was flushed and his systolic and diastolic pressures were 180–100, respectively. Twenty minutes later they were 160–90, and an hour later 126–80. His colour was now normal and he was sleepy. (Chart IV.)

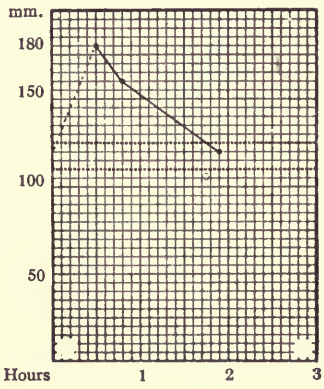

CHART IV.—Hypertension following a trivial wound.

Examination of large numbers of wounded made it possible to divide wound shock into primary and secondary varieties.

Primary Wound Shock.—Serious wounds did not always produce shock. Where, however, the damage sustained by the body was such that anatomical death must have supervened unless surgical intervention was possible or available, the pressure fell with great rapidity and the symptoms of wound shock were found to have become established as soon as the patient was seen. In war surgery at any rate it is doubtful if such a state of affairs occurred apart from hæmorrhage. To this class of case the name "primary wound shock" is given. It is an unavoidable condition, but one which in favourable cases may be kept from progressing and may terminate in recovery.

The following illustrative cases of primary wound shock may be quoted :—

Case 1. An ambulance driver, as he stepped off his car on arrival at the dressing station one bright sunny morning, was hit in the abdomen by a shell fragment. He fell down, was carried in, and put on the dressing table at once. As he was being attended to, he drew the attention of the medical officer to his profuse sweating. When seen 30 minutes later as he passed the next post on his way to the operating centre, he complained of severe pain, looked pale, and was still sweating profusely. His hands were cold and clammy, pulse 96, pressure 100-70. On his arrival at the clearing station an hour later his pulse was only 100, but the pressure had further dropped to 82-70. Operation was immediately performed, hæmorrhage stopped, and ten rents in the bowel repaired. The man's condition was serious for some hours, but he responded to treatment and eventually recovered. (Chart V.)

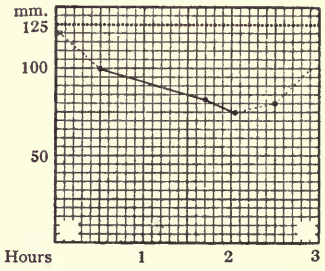

CHART V.—Primary wound shock, Case 1, ambulance driver.

Case 2. On a cold, wet, muddy night while digging a new trench a man was seriously wounded by a shell. He was brought to the advanced dressing station 50 minutes later and found to have sustained severe multiple wounds, including compound fractures of femur and humerus. The exposed lacerated muscle looked like dead tissue, there were no vessels of any size bleeding, and hardly any capillary oozing. The blood pressure was 40 mm. Mentally the patient was quite bright and responsive, so that the medical officer in charge of the case remarked how wonderfully fit he was. The man was dead, however, within the hour. (Chart VI.)

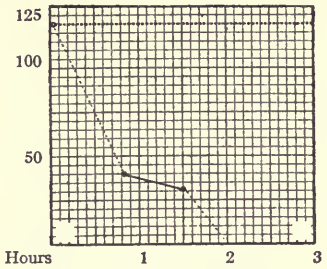

CHART VI.—Primary wound shock, Case 2, severe multiple wounds.

Secondary Wound Shock.—In a large proportion of the serious wounds symptoms of shock did not supervene until after the lapse of some hours. Early observations might show no alteration in pulse-rate or blood pressure level. During the next few hours, however, in the presence of certain factors, the pressure was found to fall, the pulse-rate to rise, and the state of shock to become established. To these cases may be given the name "secondary wound shock." Two cases are here given where wound shock did not develop, although its onset might have been expected.

Case 3. One dark night the driver of a gun team was hit in the abdomen by a small shell fragment. He got off his horse to make inquiries for the dressing station and then rode nearly a mile before being seen by the medical officer. He was then quite fit with a blood pressure of 120 which did not drop either before or after admission to hospital. At the operation two small rents in the small bowel were found and sewn up.

Case 4. One evening a man on a ration party was hit in the thigh by a shell fragment at the moment he was passing the entrance of the aid-post. He was carried down a few seconds later and found to have sustained a compound fracture of the femur. His pressure was 120-80 and pulse-rate 72. He was immediately splinted and sent on to the dressing station, where he remained under observation for six hours, and finally reached the casualty clearing station without at any time showing hypotension. (Chart VII.)

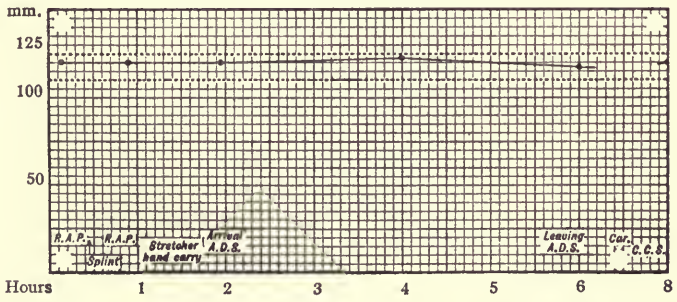

CHART VII.—Compound fracture of the femur caused by shell fragment. Thomas' splint. Absence of wound shock.

In the next two cases the wounds were by no means serious in themselves, but secondary wound shock developed.

Case 5. A man belonging to the garrison, whose pressures are recorded in Chart II, was wounded by a bomb which partly shattered the forepart of his foot and sprinkled his neck and shoulder with tiny fragments. The man standing by his side was killed. The blood pressure, which was 100–70 a short while previously, was still the same immediately after he was wounded. It was a cold night with a chilly wind, and as the man was carried shoulder-high along shallow trenches winding over a hill, he became colder and colder. At this time too there was occasional enemy activity. By the time he reached the aid-post, an hour and a half later, he was pulseless. Two hours later, when examined at the next post, he was still pulseless and a serious view was taken of his condition. He was hurried on to the casualty clearing station, where he arrived with a pressure of 80–65 and no palpable pulse. After being warmed up in bed the pulse soon returned and the shock passed off in the absence of any heroic measures of treatment. (Chart VIII.)

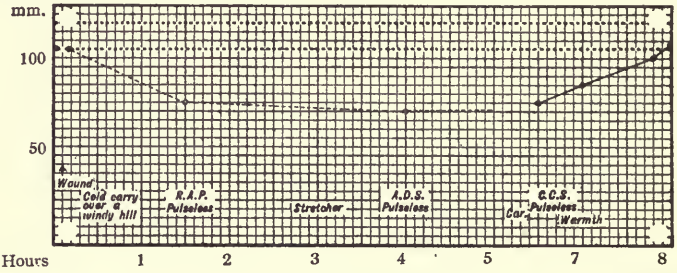

CHART VIII.—Secondary wound shock. Case 5, bomb wound of neck and foot, not severe.

Case 6. Early one night in October a young soldier on a wiring party sustained two simple perforating machine-gun bullet wounds through the fleshy part of the thigh. There was no extensive laceration of the muscles and no hæmorrhage. After a two hours' carry in the cold he was seen at the aid-post. His condition appeared grave, his face was pale and cold, with blue lips and anxious expression. He complained greatly of thirst, presented a small, thready pulse and a blood pressure of 70–50. He was given a hot drink, was well wrapped up and sent on. In the next hour, while continuing his journey under these conditions, he recovered so well that the medical officer who made the next observations could not understand why a serious view had been taken of this patient. By this time the pressure had risen to 120–80 and did not fall again. (Chart IX.)

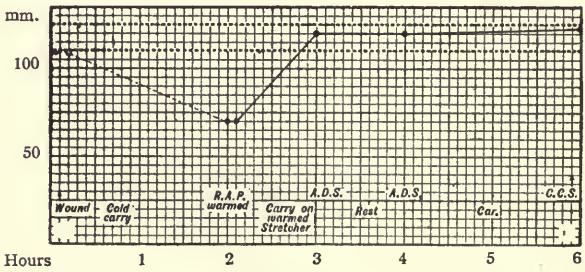

CHART IX.—Secondary wound shock, rapid recovery. Case 6.

The following cases deal with the amputation of limbs by gunshot wounds and the question of toxæmia playing a part in the onset of shock.

Case 7. In a communication trench about two o'clock one morning a stretcher party was met carrying a man with his leg blown off. At the aid-post the patient was found to be a strong burly lance-corporal with some reputation as a boxer in the battalion. He had been wounded about an hour before by a trench mortar, which had carried away his left leg a hand's-breadth below the knee, and at the same time severely injured the right tarsus. He lay quite calmly on his stretcher and answered questions readily. The pulse was 96, and the systolic pressure 115. None of the symptoms or signs of shock were present; what little hæmorrhage there had been had stopped. The man was warmed, given as much cold water as he wanted, had his wounds dressed, was well wrapped up, and then sent on his journey. He was followed for the next three hours and frequent pressure readings were taken. After five hours his face had become flushed and the pulse-rate had crept up to 120, but the pressure remained level at 114–70. On arrival at the casualty clearing station an hour later his pressure had fallen to 88–62 and the pulse-rate had risen to 144. The muscles of the stump were found to show signs of gas gangrene. After re-amputation his condition improved, and he eventually recovered. (Chart X.)

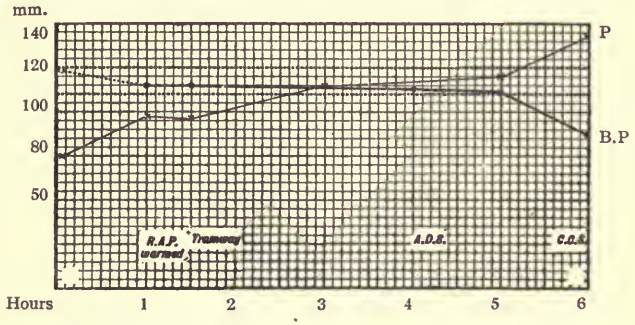

CHART X.—Gunshot amputation of leg, secondary shock with onset of toxæmia.

This case was regarded at the time as an example of bacterial toxæmia. McNee and others have drawn attention to the speed at which anaërobic infections may become established and produce their potent effects. Recent work by Bayliss and Cannon, which will be discussed in detail later, introduces the possibility of a new factor, that of absorption of the toxic products resulting from disintegration of muscle tissue apart from infection. In this, if immediate amputation had been performed, or at any rate a ligature tied round the stump to prevent absorption, the secondary wound shock would in all probability have been averted. In the next case this principle of treatment was adopted with success.

Case 8. A strong muscular soldier received a severe shell wound of the left arm, shattering the humerus. Within a short time the medical officer in the trenches, who was familiar with the view expressed in the preceding paragraph, saw the man and performed immediate amputation under an anæsthetic, thereby removing all the traumatized tissue. Four hours later, at the next relay post, the patient was pale but quite fit, with a maximum blood pressure of 140 and pulse-rate of 90.

It has been frequently noted clinically that a patient under operation for removal of a shattered limb would show an increase in pulse-rate and respiration with lowering of the blood pressure a few minutes after the tourniquet had been relaxed. Latterly it was taught that in cases where the application of

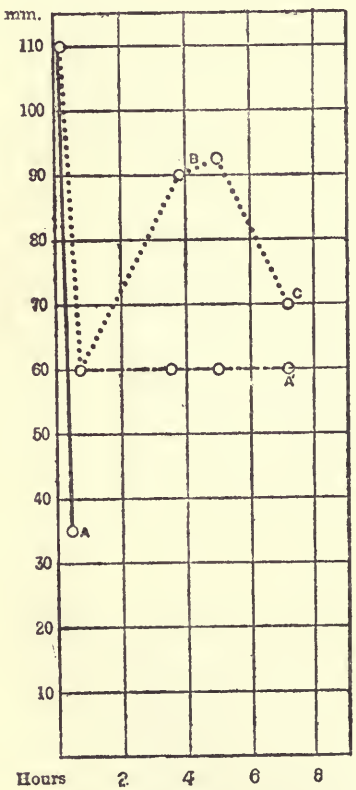

Chart XI.—Primary wound shock curves (diagrammatic). Following a severe anatomical injury, instant wound shock may develop, which may be fatal in a shorter or longer time, as shown at A or A'. Under favourable circumstances the pressure may rise to B, dropping later to C. At this point the primary has merged into secondary wound shock.

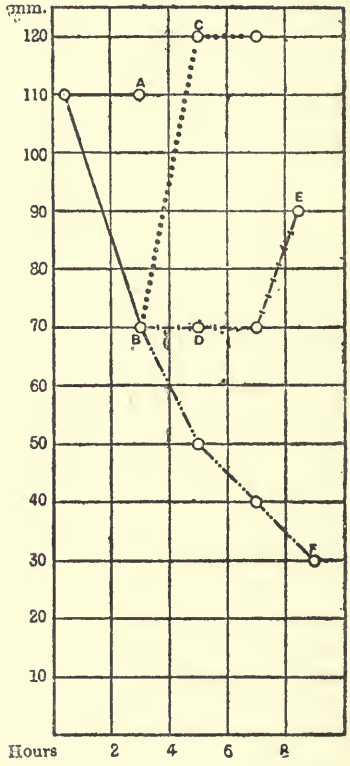

Chart XII.—Secondary shock curves (diagrammatic). In many of the cases of moderately severe wounds the pressure will remain level at A. In others it falls with the establishment of secondary wound shock, B. At this point the patient may react quickly to treatment, C, or after more prolonged treatment at D, to E. In the absence of favourable circumstances, the pressure goes steadily down, and the case terminates fatally in from 12-24 hours, F.

a tourniquet was necessary the medical officer should apply it as near to the damaged tissue as possible, so as to allow of amputation with the original tourniquet *in situ*.

Relation of Primary to Secondary Shock.—Chart XI shows diagrammatically the possibilities in a case of primary wound shock. From a practical point of view the importance of watching the patient closely during the period immediately subsequent to the onset of shock cannot be too urgently insisted on. Otherwise the favourable moment (B) will be missed, and the primary merge into secondary shock without the patient being given the benefit or opportunity of surgical intervention. The behaviour of the blood pressure in secondary wound shock is shown diagrammatically in Chart XII.

Aggravation of Wound Shock by Surgical Operation and Other Factors.—Marshall has published records of the blood pressure in the wounded during operation. The following are a few illustrative charts from cases observed by Cowell and Fraser :—

Case 9. This patient came into the hospital within 20 hours of receiving a gunshot wound with fracture of the right fibula. On admission the maximum pressure was 130, which fell to 120 at the end of the first operation. Next day gas gangrene developed, necessitating the amputation of the limb. After operation the pressure had fallen to 80. It was recognized that the cause of toxæmia was now removed, and that there was no hæmorrhage to treat. The patient was kept warm, given plenty of fluids, and in a few hours the blood pressure had completely regained its former level. (Chart XIII.)

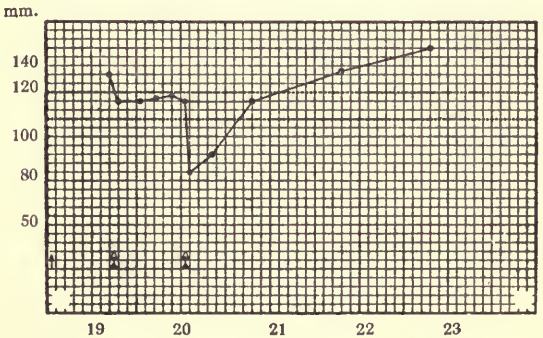

CHART XIII.—Primary surgical shock, spontaneous recovery. The arrow indicates receipt of wound, and the other signs (1) operation and (2) amputation for gas gangrene. Figures below chart=hours.

Case 10. The patient was admitted 12 hours after sustaining a shell wound of the thigh. At the operation the fragment was found to have torn the femoral vein, and the patient lost a certain amount of blood before the vein could be sufficiently exposed to be sutured. The pressure fell from 118 to 90 mm., and in this case was immediately restored by an intravenous injection of gum saline. Fifteen hours later the shock-like condition so often

associated with the presence of gas gangrene infection was observed. This necessitated excision of the affected muscle (sartorius) and a further intravenous injection of the gum saline. (Chart XIV.)

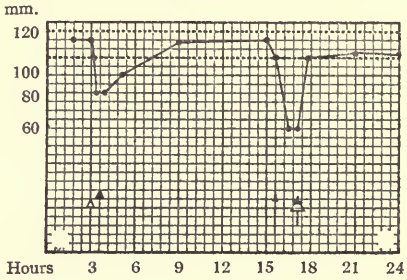

CHART XIV.—Hypotension associated with (1) hæmorrhage, (2) toxæmia. The triangle indicates operation, hæmorrhage; the next sign, injection of gum saline. The arrow denotes onset of gas gangrene; following sign, operation + gum saline.

During operations in gunshot wounds of the abdomen a fall of blood pressure may be produced by one of three conditions, as Marshall has pointed out, namely, manipulation of gut or omentum outside the abdominal cavity, occurrence of copious hæmorrhage, and change of posture at the end of operation from dorsal to lateral. Reference to Chart XV illustrates the last named cause of sudden drop in pressure.

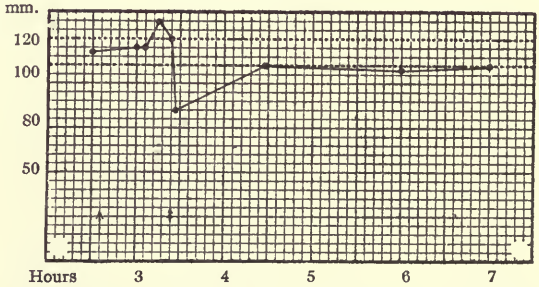

CHART XV.—Showing sudden drop in blood pressure on change of posture denoted by second arrow. Operation indicated by first arrow.

Treatment.

In order to secure universal acceptance of thorough and efficient lines of treatment in forward areas, the interest of those concerned must first be aroused and the scientific reasons for the methods suggested must be explained.

From the foregoing clinical studies of the development of wound shock in men recently wounded, it will be seen that one has to deal with primary wound shock, generally inevitable

and found accompanying the most severe wounds; and secondary wound shock, the commoner condition, which is to a great extent preventable.

The factors which have chiefly to be combated are (1) hæmorrhage, (2) cold, (3) pain and (4) toxæmia (bacterial and otherwise).

Details of treatment are well set out in the following "Hints for the Prevention of Wound Shock," drawn up by the late Captain A. A. Parker, C.A.M.C., which were circulated to the front line medical units of the First Army in 1918.

"(A) Factors in the production of Wound Shock:—

1. Bleeding.
2. Cold.
3. Pain.
4. Infection.
5. Thirst.

(B) Prevention of Wound Shock:—

1. Control bleeding by the following:—
   (*a*) Firm bandaging.
   (*b*) Ligature of bleeding vessels.
   (*c*) Packing deep wounds with gauze.
   (*d*) Application of a tourniquet; this should be used only when all other methods have failed.
2. Combat cold by the following:—
   (*a*) Removing no more of patient's clothing than absolutely necessary to dress the wound.
   (*b*) Applying blankets as soon as possible after a man is wounded. Blankets should be placed under as well as over the patient and should be pinned.
   (*c*) Always giving a hot drink, except in abdominal cases.
   (*d*) Warming with artificial heat when necessary; primus stove, brazier or warming chamber may be used for this.
   (*e*) Applying hot water bottles or hot bricks.
3. Combat pain by the following:—
   (*a*) Efficient dressing and splinting.
   (*b*) Dressing wound once and not redressing unnecessarily.
   (*c*) Placing patient in most comfortable position.
   (*d*) Careful carrying and handling of patient.
   (*e*) Careful loading and driving of motor ambulance cars.
   (*f*) Silence about the dressing room, but cheerfulness.

(*g*) Giving morphine. This should be used only when necessary and rarely in doses greater than ¼ grain. When used it should be given early.

4. Combat infection by the following:—
   (*a*) Dressing wounds carefully and not putting anything into them.
   (*b*) Rapid evacuation.
5. All wounded men need drink."

As regards combating cold, medical officers should train their stretcher bearers to carry a blanket with the stretcher when practicable. A convenient method for doing this and keeping a dry blanket with a stretcher party on detached duty is as follows:—

A service blanket is folded four times, as shown by the dotted cross lines in Fig. 1. This is placed lengthwise on a waterproof sheet, and again folded four times with the edges of the sheet turned as in Fig. 2. A packet the size of a stretcher pillow is thus produced (Fig. 3), which is doubled and carried in the closed stretcher in the usual way. To prevent its slipping, the "packet" is secured by two pieces of white bandage, which can be easily undone at night (Fig. 4).

By the use of this "blanket packet," men hit when on a working party or in a part of the line at some distance from a regimental aid-post, can be prevented from becoming chilled during the first part of the journey to the hospital. Observation has shown that it is during exposure to cold, for perhaps two hours or more passed on this tedious and hazardous stage of the journey, that secondary wound shock is especially prone to develop.

At the aid-post arrangements must be provided to apply heat to the wounded man during the examination and dressing of his wound. This is easily done by placing a guarded primus stove or small brazier under the stretcher. Before the patient is placed on it three blankets should be arranged so that four folds of blanket are beneath him as well as on top. (Figs. 5 and 6.)

The man must be given plenty of fluids at this stage, preferably hot tea, but cold water seems to be equally useful and all wounded men should be encouraged to drink. It has been noted that with a pressure below 70 mm., the patient usually complains of intense thirst. Hot bottles or bricks are now applied, one to each axilla and one over the lower abdomen. These are the most favourable situations for applying heat

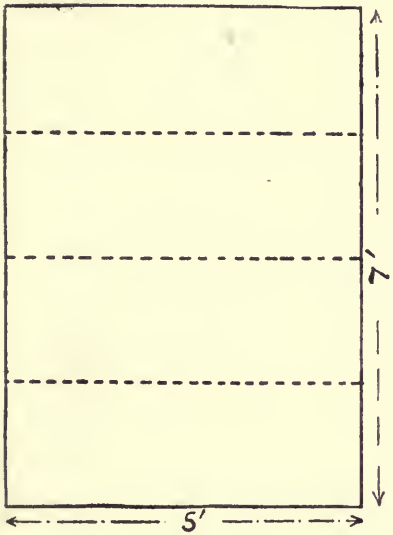

FIG. 1.

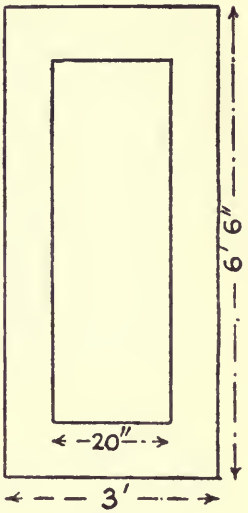

FIG. 2.

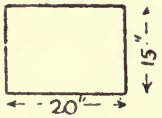

FIG. 3.

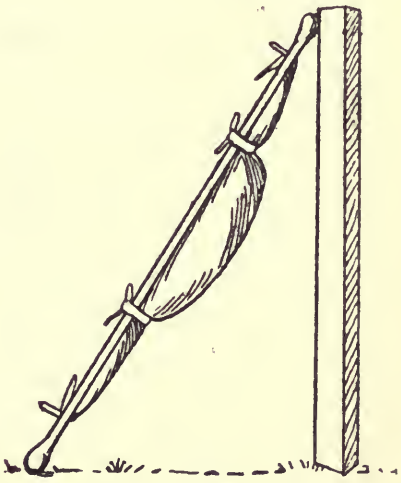

FIG. 4.

The "Blanket-Waterproofsheet-Packet" made to carry in a stretcher.

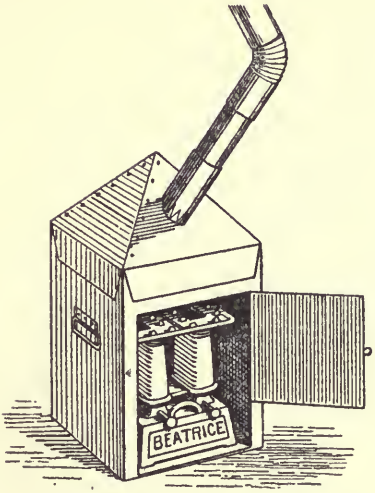

Fig. 5. Hot Air Generator.

since here the axillary and femoral arteries are immediately under the skin.* At each relay station, if necessary, the patient may be rewarmed. In this way cases of wound shock have been observed actually to recover during transit; and in many other cases, with the adoption of these precautions, no shock has developed at all, even in cases of severe wounds.

Other points to be considered in the treatment of these cases in the aid-posts and advanced dressing stations are the following:

Drugs.—Morphia is undoubtedly useful when given hypodermically or even intravenously in small doses. Large doses which produce slow respiration and cyanosis are profoundly dangerous.

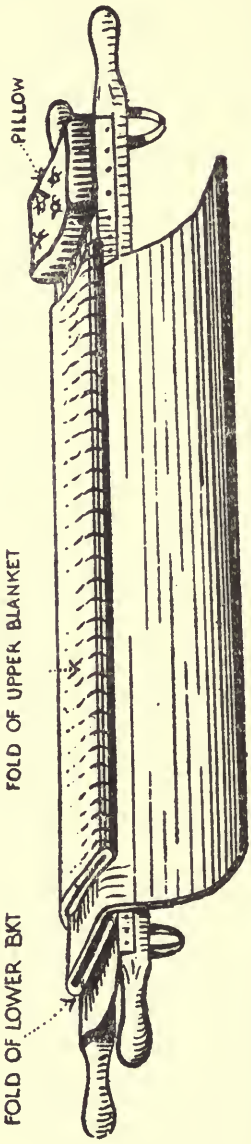

Fig. 6.

Infusion for Hæmorrhage.—Intravenous injections of gum saline have been practised and have given good results in

* Experimentally the temperature of a rabbit may be quickly raised by surrounding the carotid artery with a Leiter's tube perfused with hot water.

certain cases. This is more practicable in the trenches than blood transfusion, although occasionally the latter has been possible under favourable conditions and has saved many lives.

Amputations.—In view of the importance of the toxic element of shock, hopelessly wounded extremities, where the limb is already partially severed or where ultimate saving of the part is impossible, should be amputated as soon as possible and instructions were given to this effect as early as October 1914 by Sir A. Bowlby, the consulting surgeon for the front areas.

Failing this, a tourniquet should be applied low down and at the most distal point suitable, so that later a formal amputation may be carried out without removing the original tourniquet.

It must be remembered that not only does a really tight tourniquet stop both bleeding and absorption, but it quickly produces complete anæsthesia of the wounded limb below the site of application and so saves that element in shock which is due to pain.

Finally, during transport from the advanced dressing station to the casualty clearing station in a motor ambulance car, care must be taken to provide as much warmth as possible. The car may be heated by pipes conducted back from the exhaust, or better, in the case of small cars, by electric warmers placed near the stretcher or under the blankets.

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CHAPTER IV.

WOUND SHOCK IN CASUALTY CLEARING STATIONS.

AN account of the pathology of wound shock must necessarily include a consideration of the more important work which had previously been done in attempts at the elucidation of this most interesting problem. It is an educative experience to read "A Summary of Shock" which was written by Mansell Moullin in the International Encyclopædia of Surgery in 1882. It is a striking fact that many of the theories which now rank as modern were suspected and even enunciated at that time.

Keen in 1864 enunciated a theory very similar to that which Crile teaches at the present day, and H. Fischer six years later carried out experimental work which appeared to confirm Keen's theory that shock was essentially a vasomotor phenomenon.

These details are now, however, of no more than historical interest, but one more reference may be made to the older work, and that is to a publication by Leyden in 1870, in which he apparently satisfied himself that shock was primarily the result of a reflex inhibition of the activities of the nerve centres of the spinal cord.

Previous to the subject being taken up by the special committee of the Medical Research Committee in 1916, opinion had definitely crystallized itself around certain theories; each of these put forward claims and propositions. Something may be learned from considering very briefly the more reasonable of these theories.

Theories of Shock.

1. *The Crile-Mummery theory—exhaustion of the vasomotor centre.*—The reasoning followed was that sensory stimuli produced a rise of blood pressure from the irritation of "pressor" nerves. The continuation of these afferent stimuli led eventually to exhaustion of the vasomotor centre and a subsequent fall of blood pressure. It was further pointed out that in certain cases only a depressor afferent nerve existed, while in others the shock values varied, irritation of some inducing much more shock than irritation of others.

The criticisms directed against this theory came primarily from two sources :—

(a) In shock the vessels were said by Malcolm and by Seelig and Lyon to be contracted and not dilated.

(b) The vasomotor centre is not exhausted according to Seelig and Lyon, Porter and Quinley.

2. *The Henderson theory—the acapnic theory.* Haldane and Priestley hold that the respiratory centre depends for its activity on the amount of CO_2 in the blood. Excess of CO_2 produces stimulation of respiration; a diminution of CO_2 produces several deep respirations and a pause in the respiration called "apnœa."

According to Y. Henderson, the deep and rapid breathing which is induced by painful stimuli reduces the CO_2 to a very low figure—acapnia—and this in his opinion is the primary cause of shock. He attributed the fall of blood pressure to a failure of the venous pressure, to the accumulation of blood in the venous spaces and to impoverishment of the right auricle.

Henderson further attempted to show that when the abdomen is opened and the intestines exposed, there is relatively a great loss of CO_2 from the visceral surfaces, forty times as great as from the skin, and that locally changes of vascular dilatation, muscular paralysis, apnœa occur and finally general shock.

In later confirmation of his theory, Henderson quoted experiments by Sherrington and Copeman which seemed to indicate that a diminution of CO_2 produces a great tendency for fluid to exude from the plasma into the tissues, leaving the blood concentrated.

The sequence which Henderson claimed may be summarized as follows :—hyperpnœa, acapnia, failure of the vasomotor pressor mechanism, venous anoxæmia, tissue asphyxia, acidosis, acute oligæmia.

Finally, it is interesting to observe the treatment of shock which Henderson recommended. He advised slow respiration, breathing through a long tube so that expired air loaded with CO_2 was re-breathed, pouring warm saline saturated with CO_2 into the abdominal cavity, transfusing warm saline saturated with CO_2, allowing the subject to breathe in and out of a bag containing air or oxygen.

The Crile-Mummery and Henderson theories were the two which found most acceptance, but other views were put forward by various observers, which need only be mentioned.

3. *The Boise theory.*—Boise recognized the importance of the fall in blood pressure, and he ascribed this to a failure of the

heart in systole. In support of his assertion, he quoted the very vague circumstance that in animals dying from shock, the heart is contracted. Boise firmly believed in his own contention and suggested a practical line of treatment based upon it. He recommended the use of veratrum viride, which lessens systole and prolongs diastole.

The fallacy of Boise's theory can easily be demonstrated, for the heart is not primarily weakened in shock, as is shown by the fact that, when blood or gum solution is infused, the blood pressure rises to its normal height.

4. *The Meltzer theory.*—This theory is based upon the recognition of a clinical fact, that when the abdomen is opened or even when an extensive skin dissection is made, there is an inhibition of the peristaltic movements of the intestine.

In a more severe injury Meltzer believed that the functions of the spinal cord were inhibited, leading eventually to an inhibition of the medulla and its centres. It need only be said that there is no evidence that such a reflex inhibition of the spinal cord exists.

Other theories were put forward from time to time but do not merit special mention here.

Clinical Pathology.

The clinical picture of established wound shock is one which in many respects is characteristic. The patient may be described as being in a state of prostration. He is roused with difficulty from what appears to be a condition of mental indifference yet he answers questions clearly and intelligently, if faintly. The face is drawn and pale, beads of perspiration stand out on the brow, the eyes are sunken and the cheeks hollow. The lips and ears are pallid. The body surface is grey in appearance, being cold and clammy to the touch. The pulse is rapid and fluttering, and often imperceptible at the wrist. The respiration is irregular, shallow and sighing, and the temperature of the expired air is abnormally low. The general body temperature is low. The mouth is parched and the patient complains of thirst. There is diminished sensibility to pain.

Such was the picture shown by a man in a fully established condition of wound shock, but the intensity of the features varied in different degrees. Except in severe cases there is a natural tendency towards recovery, and when this period is entered upon it is spoken of as the stage of reaction. It is often ushered in by vomiting. The colour improves, the

pulse becomes full, the respiration deepens and becomes more regular, the temperature rises. There is a noticeable improvement in the psychological condition, and the mental indifference of the early stage disappears.

Of the outstanding groups of clinical features which these cases present, there are four which may be said to be primary :— (1) circulatory disturbances, (2) respiratory disturbances, (3) motor disturbances, and (4) sensory disturbances.

Circulatory Disturbances.—The clinical features which can be attributed to circulatory changes are the low arterial blood pressure, the small thready pulse, the pallor of the body surface, and the low temperature of the skin.

There are three active factors which maintain the blood pressure at a normal level, namely, the contracting heart, the bulbo-vasomotor mechanism which regulates the tonicity of the vessel walls and the volume of the blood. Investigations have been carried out to determine whether there is any evidence which would point to one or other of these being the factor responsible for the circulatory changes.

Howell suggested that in shock there is a paralysis of the cardio-inhibitory centre which results in an increasing rapidity of the heart-beat, and therefore in a weakening in its efforts. Howell's suggestion was contradicted by Mann's experiments, for these showed that even in deep shock, stimulation of the central end of the cut vagus resulted in the characteristic reflex slowing of the heart.

If further evidence on this point is required it may be found in two other facts, namely, that an administration of adrenalin, from its effect upon the centre, causes dropped beats which could only occur when the centre is responsive, and that an increase of intra-cranial pressure, when it occurs in pronounced shock, stimulates the cardio-inhibitory centre and slows the heart. The evidence of these facts would appear to indicate that the nervous control of the heart is not interfered with.

To quote Mann's experimental work again, it would seem that as long as the heart is properly supplied with blood there is an efficient contraction of the cardiac muscle. A persistent low blood pressure, of course, incapacitates the heart (according to Markwalder and Starling), but the essential point is that in surgical shock there is no primary error in the functional power of the heart.

It was a very natural assumption that the low arterial pressure so characteristic of surgical shock was due to a relaxation of the arterioles. This view was expressed many years

ago by Mitchell, Keen and Morehouse, and more recently was elaborated by Crile. The bulbo-vasomotor mechanism, being the centre which controls the arteriole tone, was said to be exhausted. Without quoting any detailed evidence against such an assumption, for such evidence is now well accepted and recognized, it may be said that there is no appearance of paralysis of bulbar centres in the early stages of shock. Prolonged low blood pressure by direct interference with nutrition leads to exhaustion of the centres, but this is purely a secondary result. In experimental shock the bulbo-vasomotor centres retain a nearly normal excitability for some time after the state of shock has developed.

It is very likely that a temporary collapse of the centre occurs on incidence of the injury, but such is of the nature of a functional inhibition. The fact must not be lost sight of, that this primary inhibition may play a part in the production of later true shock, but the essential point is that there is no exhaustion of nerve centres (vasomotor) through a reflex origin.

Linked up with the question of exhaustion of the nerve centres is the possibility of arterial or venous paralysis, especially of the splanchnic vessels. This possibility would appear to be excluded by surgical evidence obtained at operation on cases of established shock. No appearance of distension of arterioles or veins in the splanchnic area was ever found in these cases. It may be asked whether there was not the possibility of error that previous hæmorrhage had so emptied the vascular system as to prevent distension of the relaxed blood vessels. The answer is that the observers had this possibility in view, and the examinations were made in cases where the possibility of severe hæmorrhage could be excluded.

Now if the vasomotor centre is not exhausted, the question arises as to what is its actual condition in shock. The evidence obtained in recent observations points towards an efficient contraction of peripheral and visceral arterioles. Indeed, the skin pallor, so characteristic of shock, would seem to indicate a peripheral vaso-constriction. The sweating and the pupil dilatations would indicate that the sympathetic nervous system, too, is active. The experimental evidence of the activity of the vasomotor mechanism is clearly established, and may be found in the publications of Seelig and Lyon, Guthrie, Seelig and Joseph, Morrison and Hooker.

Crile and Dolley recount histological evidences of exhaustion of nerve cells in the central nervous system. The inference

which these observers drew was open to criticism from several sources, and Mott undertook an investigation of the central nervous system of a case of shock. He drew attention to the similarity in every respect of the changes which he found to those which he had experimentally produced by ligaturing all the arteries carrying blood to the brain. He regarded the whole of the nerve cell changes as a secondary result of intense cerebral anæmia, due to the prolonged low blood pressure.

If the heart and its associated nervous mechanism are efficient and the bulbo-vasomotor centres are unimpaired, it remains to be considered whether the fall in blood pressure is due to an alteration in the blood volume. A diminution of the volume of blood in circulation would explain the low arterial pressure.

Henderson has pointed out the necessity for a sufficient supply of blood to the heart in order to maintain the arterial pressure at its normal level. In the absence of supply, *e.g.*, in hæmorrhage, the arterial pressure falls to a low level, and can only be permanently raised by introducing more fluid into the circulation. There is evidence to show that in cases of established shock there is a diminution in the volume of blood in circulation. This evidence has been obtained by the use of the vital-red method, and the results of investigation have been published by Keith, Robertson and Bock.

It having been established that the blood volume in active circulation is diminished, and assuming that the loss cannot be accounted for by hæmorrhage, the question naturally arises as to where the blood goes when it passes out of active circulation. Cannon has put the question in an appropriate form when he talks of "the problem of the lost blood." Until recently the question was answered by the reply that the "lost" blood lay in the splanchnic area. The fact that the experimentalist proved this point to almost general satisfaction, and yet, as has already been stated, clinical observation at operation failed to confirm the view is, perhaps, an illustration of the danger of relying too much on pure experimental evidence. The experimental aspect of the question is fully dealt with in the publications of Mann and Morrison and Hooker.

It must be acknowledged that the view that the splanchnic area is the "locale" of the lost blood strikes the observer as being a most feasible proposition, and, though it appears to be contradicted by clinical observation, it is probably unwise

to dismiss it entirely. It is quite possible that to some degree the splanchnic region may form a catchment area, and there are physiological reasons in favour of this. The portal circulation is almost unique in its arrangement. In it there may be said to exist two capillary regions, the capillaries of the stomach, intestines, pancreas and spleen and the capillaries of the liver. A considerable amount of work must be done to drive the blood through such a double system of fine blood vessels, and from the aortic level of 120 mm. of Hg. there is a fall to the portal level which is 10 to 12 mm., and a further drop in passing through the liver to zero pressure in the inferior vena cava. There is, therefore, a mechanical reason why there should be a tendency to stagnation of blood in this area.

There is another reason, however, which must be quoted. Bayliss and Starling have brought forward evidence of the existence of a nervous government of the portal branches. Cavanzzani and Manca have also reported that induced asphyxia lessens the rate of flow of blood through the liver vessels, and this they believed they could explain by the increase of activity of the vasomotor centre in asphyxial conditions. Similar evidence has been brought forward by Schmid and Opitz, who used in their experiments electrical stimulation and the injection of adrenalin.

If, then, there is vasomotor control over the hepatic vessels, and if there exists a vasomotor activity during the early stages of shock, it is possible that the resulting constriction may lead to an accumulation of blood in those vessels of the splanchnic area which lie behind the contracted vessels. Unfortunately from the clinical standpoint it is impossible to confirm or deny such a possibility, and the only evidence is that already quoted, which is rather against such an occurrence.

There is, however, another " locale " where the lost blood may collect, and recent work indicates that this is the main area of stagnation. The area referred to is the superficial capillary system, more especially of the body surface. Captain Emrys Roberts, working in No. 15, afterwards No. 21 (Welsh) Mobile Bacteriological Laboratory, noted that in cases of shock, the red count of blood taken from superficial capillaries is considerably higher than that taken from the blood in active circulation in the veins. The discrepancy is greater the more profound the shock, and not infrequently it is as much as 2,000,000 corpuscles per cubic millimetre. Since the venous count is approximately normal, the condition is

due to a stagnation of corpuscles in the capillaries. The observations, by means of blood counting, have been confirmed by hæmatocrit and hæmoglobin determination. This condition once established in shock, recovery from it is only gradual. The recovery sometimes requires two or three days, according to Cannon, Fraser and Hooper.

It is impossible to estimate how much blood passes out of active circulation secondary to the peripheral stagnation and concentration, but it is not unreasonable to assume that this development may account for the reduction in blood volume to which attention has already been drawn.

What may be termed the clinical pathology of the circulatory changes observed in shock may therefore be summarized as follows :—

(1) There is a marked and progressive fall in arterial blood pressure.

(2) The heart and its nervous mechanism are not primarily involved or affected, but a persistent low blood pressure will eventually interfere with its functional ability.

(3) The bulbo-vasomotor centre shows no sign of paralysis in the early stages of shock. There may be a momentary depression at the period of the injury, but this is purely inhibitory. There are indications that in the early stages the vasomotor centre may even be more active than normal. With the continuance of a low blood pressure, the centre suffers from deprivation in common with other tissues.

(4) There is a reduction of the blood volume in shock, and apart from cases of hæmorrhage, the reduction is probably to be explained by a stagnation and concentration of blood in the superficial capillaries.

Respiratory Disturbances.—Shock respiration is of the superficial, rapid type, and is very similar to that with which the clinician is acquainted in toxæmias and after severe hæmorrhage. The shock victim breathes rapidly. There are occasional deep sighs or gasps, and at intervals there is what can only be described as a quick respiratory "flutter."

Y. Henderson in his "acapnia" theory claims that the respiratory change is the primary factor in shock, that painful stimuli give rise to such extremes of pulmonary ventilation as to diminish the CO_2 content of the blood and so to produce an acapnia, to which he ascribes the circulatory phenomena

of a shocked case. There are certain objections to this view. In shock the respiration is essentially shallow, and, as Edsall has pointed out, in superficial respiration the gaseous exchange occurs more and more in the " dead spaces," *e.g.*, trachea and bronchi, in so far as the respiration becomes less and less deep. Therefore it is reasonable to assume that the effect of shallow respiration will be to increase rather than to diminish the CO_2 content of the blood.

The second objection to Henderson's theory is a more potent one. If the " acapnia " view had been correct, the body in shock would show a diminished amount of CO_2, but as Janeway and Ewing have shown, the CO_2 content of the body is not reduced, and this observation has been confirmed by Rendall Short in regard to the venous blood in shock.

If the respiratory changes are therefore not primary, some explanation must be afforded in so far as they are secondary to some other change. There are possibly three factors which so affect the respiratory centre as to produce the effects described.

The blood pressure associated with the condition of shock and the diminution in the amount of circulatory blood will reduce the O_2 carrying power of the blood. It is known that reduction of the oxygen carried by the blood to the central nervous system produces a hyper-irritability of the various nerve cells and centres, and this is undoubtedly one of the explanations of the rapid respiration of the shocked condition.

The second possible factor producing the characteristic respiratory change is one upon which opinion is not yet decided. It is the exaggerated Hering-Breuer reflex described by Haldane. One word of explanation is necessary in regard to this reflex. As the lungs are being stretched by the action of the respiratory muscles, certain nerve-endings or receptors are stimulated. When stimulation has reached a certain point, this inspiration is inhibited and expiration is excited. Under certain abnormal conditions, inhibition occurs early in the course of inspiration, and a rapid, shallow respiration therefore results. Both wound shock and hæmorrhage appear to constitute these abnormal conditions, but whether the effect which produces the irritability is exercised upon the " receptors " or upon the respiratory centre is undecided.

This leads naturally to the last factor which affects the respiratory centre. Owing to the ineffective nature of shallow breathing there is an abnormally high carbon-dioxide content in the blood. At the same time there is, for reasons which

are discussed elsewhere, a reduction of the bicarbonate salts of the body. The result of these changes, the increase of CO_2 in the blood, and the reductions of the body alkali, is an increase in the hydrogen-ion of the blood.

Now Haldane and Priestley have shown how extraordinarily sensitive the respiratory centre is to a slight increase of the hydrogen-ion concentration, and the type of respiration which occurs is not of the rapid, shallow type, but of a rapid, deep character. It is, in fact, an effort of the body to get rid of the carbon dioxide by increased ventilation of the lungs. This type of respiration is sometimes seen in the terminal stages of shock, but it is probably more correct to say that when this type of respiration occurs the condition has passed out of the domain of surgical shock, and entered that of acidosis.

There is a final consideration which may have a bearing upon the respiratory changes in shock. Edsall points out that very rapid breathing may abolish entirely respiratory blood pressure changes. It is possible that this is an important safeguard for the heart, because, with a greatly reduced arterial pressure, a further diminution, such as would occur with each deep respiration, might so lower the pressure as to diminish the flow through the coronary arteries and so impair the cardiac contraction.

To summarize these points :—

(1) The respiratory changes are not primary, but secondary in character.

(2) The factors which affect the respiratory centre are the low arterial pressure with its associated diminution in the CO_2 carrying power of the blood, an exaggeration of the Hering-Breuer reflex, and in certain terminal cases an increase of the hydrogen-ion content of the blood with direct stimulation of the respiratory centre.

(3) The characteristic respiration in shock is of a rapid, shallow character. If an acidosis effect come into play, the respiration becomes deep and rapid.

Motor Disturbances.—The characteristic motor disturbance of shock is an increasing motor weakness which eventually extends into what one may term a general muscular apathy. It has been suggested that the motor changes are the result of repeated sensory stimuli, which, being converted in the central nervous system into motor impulse, eventually lead

to a physiological block in the motor tracts. Sherrington has disproved this possibility. He has shown that if stimuli be repeated so as to produce a block in the afferent paths, and therefore a failure in the reflex, the reflex is at once produced if a new afferent path be chosen. Therefore, the motor mechanism is less affected than the sensory in repeated stimulation.

The explanation of the motor changes is to be found in the low arterial pressure. Gruber has proved that when the systolic pressure is reduced below 90 mm., the muscles as contractive organs become less capable of work. The whole central nervous system shares in an impaired nutrition secondary to the lowered blood pressure; the afferent tracts and sensory cells, the synapse motor cells and tracts, are equally affected. It is, therefore, not surprising that in the victim of shock there is a general relaxation of the body musculature, with irregular and feeble movements, and a slowing and weakening of central nervous functions.

These remarks are intended to apply more especially to striped or voluntary muscle. Involuntary or non-striped muscle, *e.g.*, the alimentary canal, is also inhibited, but its inhibition has a different explanation from that of voluntary muscle. In the case of the non-striped muscle the inhibition would appear to be due to activity of the sympathetic nervous system.

Sensory Disturbances.—One of the most striking evidences of shock is a diminished sensibility to stimulation. The blunting of sensation and the general apathy are features which have been emphasized in all the clinical accounts of the shocked state. The physiologist has long recognized this. One of the methods of inducing shock in an animal consists of exposing and manipulating the intestine. As the condition of shock gradually develops the animal becomes progressively less responsive to stimuli, restlessness disappears, and there is a distinct reduction of sensitiveness of the entire body. This is a close parallel to the features which are distinctive of shock in the human subject, and therefore it is of interest to know how the physiologist explains the features which he has observed experimentally.

Sherrington's explanation is that the ingoing impulses are blocked at the junction or synapse between the afferent nerve cells or neurones, and neurones lying wholly within the central nervous system. The phenomenon of " blocking " he accounts for as due to an increase of the natural resistance at the synapse

to such a degree that the impulses fail to pass. By this means the body as a whole would be protected against the effects of repeated stimulation along a given course.

Further information may be demanded as to why there should be such increased synaptic resistance in shock. The injury accounts for the afferent stimuli, but, as Porter's experiments have shown, another feature comes into play, namely, low arterial pressure. Porter studied the effect of low blood pressure on the minimal strength of a stimulus required to evoke a reflex in the spinal cord. He found that with a uniform elevation of arterial pressure the threshold stimulus for the reflex remained practically uniform. If the blood pressure is lowered the threshold rises, the synaptic resistance increases, and an increasing strength of stimulus is required to call forth a reflex.

In Porter's experiments the minimum stimulus rose from 40 units to 110 solely as a result of the lowered arterial tension. The lowered arterial tension may of course be read as a diminished amount of oxygen, or an increase of carbon dioxide ; both of these conditions have the effect of raising the synaptic threshold.

The evidence indicates therefore that the sensory disturbances which appear in shock are the result of an increased synaptic resistance, this being due in part to an excessive stimulation along afferent tracts and partly to a continued low blood pressure.

Morbid Anatomy.

Examination of the body after death has revealed little of importance pointing to any morbid anatomy peculiar to shock. It must be borne in mind that the majority of cases of shock are complicated by two other conditions, namely, hæmorrhage and the absorption of toxic or septic products. These complicating features may produce morbid changes, and from time to time errors have occurred from attributing such changes to shock. This possibility of error is well illustrated in regard to the changes which were said to occur in the central nervous system, chromatolysis, etc., and how these changes are the result of an anæmia, according to Mott's investigations, has already been described.

So far as present methods of investigation go, therefore, no morbid changes can be demonstrated other than those described under clinical pathology.

Other Pathological Considerations.

In the description of the clinical pathology, it has been shown that underlying the majority of the clinical changes there is a basis of arterial hypotension. In addition, investigations have brought out a number of other pathological details of which the following is an account.

Capillary Stasis and Permeability of the Vessel Walls.—Sherrington and Monkton in 1893 reported a concentration of the blood in shock, and they ascribed this to an increased permeability of the vessel wall with an escape of plasma into the tissues.

In 1916 Marshall found that the hæmoglobin percentage of the blood was increased in cases of shock. Cannon, Fraser and Hooper confirmed this in 1917, and, as noted above, Emrys Roberts showed that the red count taken from various capillaries is higher than that of blood taken from a vein, the discrepancy being greater the more profound the shock, and not infrequently amounting to 2,000,000 corpuscles per cubic millimetre. The importance of these observations hangs upon the fact that, during the progress of a case of shock, there is an increasing tendency to concentration of the blood in the superficial capillaries.

The increased permeability of the vessel walls is probably a natural result of the arterial hypotension. It has a practical application in so far as saline fluid introduced into the vessels, while they are in this condition, passes through the vessel walls with great ease. It has been suggested that, coincident with the arterial hypotension and the capillary concentration, there is a roughening of the endothelium lining the vessel walls. This suggestion has not been confirmed by histological studies.

Absorption of Toxic Products.—Cuthbert Wallace first drew attention to the increased liability to shock when large muscular masses were cut. He pointed out that in amputation of the lower limbs, shock increases as the trunk of the body is approached, and he contrasted the degree of shock in inter-scapular thoracic amputation and amputation at the hip joint. The degree of shock is infinitely greater in the latter, though the wound areas are very similar in extent. He ascribed the greater degree of shock to the amount of muscular tissue which was cut through. The experience of the war confirmed this view in many respects, and it has been repeatedly noticed that patients with compound fracture of the thigh and multiple wounds were peculiarly liable to shock.

Such observations as these were made the basis of an experimental investigation by Bayliss and Cannon. They found that within an hour after producing a compound fracture in an anæsthetized cat, the fracture being accompanied by bruising of the large flexor muscles of the thigh, the animal showed signs similar to those associated with secondary wound shock. The blood pressure gradually fell, pulse rate and respiration increased, the blood showed signs of concentration and the animal finally succumbed.

The next step in the experiment was to isolate the limb from the central nervous system and subsequently to traumatize it in the way described. The sequel was exactly similar, and this result definitely excluded the possibility that harmful afferent stimuli from the injured limb were responsible for the symptoms.

When, however, the third stage of this experiment was carried out and the return of blood from the damaged limb was prevented by means of small clips, there was no resulting fall of blood pressure. As soon as the clips were removed and the returning blood reached the body, the blood pressure fell. It may be said that the chain of evidence was complete and that the muscle destruction resulted in the liberation of a tissue poison, which, circulating in the blood, produced the deleterious signs noted.

From this point the question naturally arises as to how the tissue poison acts in producing the changes. Vincent and Sheen in 1903 found that extracts of muscle have a specific effect in producing vaso-dilatation. Dale and Richards in 1918 showed that histamine dilates the capillaries and they suggested that substances of similar action are produced by injury to tissues. The result of widespread capillary dilatation would be the "side tracking" of a considerable amount of blood into them, and the loss of this amount of blood to the general circulation would act very similarly to a hæmorrhage. This basis, therefore, affords a reasonable explanation of the serious symptoms which follow the destruction of large areas of tissue.

Dale and Laidlaw observed that after large doses of histamine, a condition developed which could only be described as one of shock, and it may be accepted that extensive destruction of body tissue by such injuries as shell wounds plays an important part in the production of wound shock through the medium described.

Body Temperature.—It is difficult to over-estimate the importance of cold as a factor in wound shock. It is possible

that it acts as one of the factors which originate the condition; it is certain that it has a powerful exaggerating effect when shock has become established. The cooling of the body surface results in a retarding of the blood flow through the superficial capillaries, and this directly leads to a lessened supply of heat to other regions of the body. The cooling also probably increases the viscosity of the blood, and thereby the blood flow in the capillaries is still further retarded. An aggravating factor in the progressive fall of blood pressure then comes into play, and as the blood pressure falls, the actual production of body heat is probably lessened.

In a series of wounded presenting low blood pressures, the temperature of the interior of the thigh muscles was found to be as low as 94° F., and even occasionally lower.

The cooling of a person in shock, therefore, is attended by a further lowering of an already low blood pressure, or by continuance of the pressure at low level.

Hypersecretion of Adrenalin.—The theory was at one time advanced that exhaustion of the suprarenal bodies played an important part in the production of shock. It was suggested that the strong physical influences which affected soldiers in action produced this deficiency and the sustaining of a wound by men in such condition was, so to speak, the lever which set in motion the cycle of shock symptoms, the symptoms being really due to the suprarenal insufficiency.

Investigation has shown that instead of suprarenal exhaustion being present, the reverse is the case. From the work of Cannon and Elliott it is practically certain that wounded men "show the presence of adrenalin in the blood," and these observations were confirmed by Bedford. Experimentally also the injection of large doses of adrenalin produces a shock-like condition in the animal according to Bainbridge and Trevan. It is possible, therefore, that an increased activity of the suprarenals may play some part in the complexity of features which go to produce wound shock, but it must be added that this rôle is of a minor and secondary nature.

Deficient Oxygenation of Body Tissues.—Of all the various manifestations of shock, a diminished blood pressure is undoubtedly the most outstanding feature. A direct result of such a continued low pressure necessarily implies a diminished oxygen supply to the various body tissues. The deleterious effect of this insufficiency of oxygen is manifest in shock, and reference has already been made to the cytolysis of central nervous system cells having been assumed at one time to be a primary factor

in shock. Mott showed that these changes, in common with those in other tissues, were secondary to an anæmia and deficient oxygenation.

Of further interest in this connection, and of great importance from the practical point of view, is the varying degree of resistance which different tissues show to diminished oxygenation. It is a fortunate provision that the vasomotor and respiratory centres of the central nervous system display considerable resistance. There is no exact information on the point, but it would seem that in man the vasomotor centre may fail before the respiratory centre.

The practical importance of these observations is the encouragement which it gives to efficient resuscitation treatment. The body tissues have a definite limit of endurance to the effects of sub-oxygenation, and this limit may be expressed in terms of the blood pressure. Clinical experience has shown that after the systolic pressure has remained at 60 to 70 mm. for from four to six hours, the patient cannot as a rule be resuscitated even by blood transfusion. Though expressed in terms of millimetres of blood pressure, it really means that under such conditions the tissue cells have suffered too long from lack of oxygen; and that the process of tissue death has advanced too far to permit of recovery.

There is the further practical bearing that any method of treating shock which tends to aggravate the sub-oxygenation of the tissues is necessarily harmful. This is the objection to the use of massive doses of morphia, for the drug by depressing the respiration increases the cyanosis, and therefore diminishes the oxygen supply to the tissues.

Relationship of Acidosis to Wound Shock.—For some time previous to the more recent investigations, physiologists had suspected that an increase of the CO_2 content of the blood played a part in the development of shock. Hooker had observed that CO_2 in minimal effective amounts caused relaxation of muscle, while O_2 was essential to the maintenance of muscle tone. At this time it was accepted as the basis of shock origin that the blood became collected in the splanchnic area, and Cannon in the Shattock Lecture of 1917 advanced the argument that an excess of CO_2 in the blood accumulated in this and exercised the effect which Hooper had demonstrated, and produced relaxation of the vessel walls with aggravation of the stagnation.

Reference has already been made to the way in which the "splanchnic" theory became discredited, but much interest

continued to circulate round the possibility of the general effects of diminution of the blood alkali in shock.

Normal blood plasma contains a certain percentage of sodium bicarbonate ; it constitutes the " alkali reserve " of the blood and one of the alkali reserves of the body. A reduction of this alkali reserve, or sodium bicarbonate, was spoken of as " acidosis " by L. J. Henderson in 1909, and van Slyke in 1917.

It is necessary, however, to draw a distinction between acidosis in the sense of Henderson and van Slyke, a mere reduction in the alkali reserve of the blood, and a change in reaction, an increase of the hydrogen-ion concentration or acidity of the blood and the tissues. The bicarbonate of the plasma always contains a weak acid in the form of dissolved CO_2, and the H-ion concentration of the plasma is determined by the ratio between the H_2CO_3 (dissolved CO_2) and $NaHCO_3$. When the bicarbonate decreases while the CO_2 increases or remains constant, the H-ion concentration rises. If the CO_2 decreases while the $NaHCO_3$ remains constant or increases, the H-ion concentration falls. If both vary together so that their proportion to one another remains constant, the H-ion concentration is unchanged. To put the matter simply, but less correctly, the acidity of the blood is due to the carbon dioxide, the alkalinity to the bicarbonate.

In early publications on shock by Henderson in 1910, the occurrence of acidosis as a secondary development was mentioned ; and in more recent publications by Crile in 1915, Morriss in 1917, Caldwell and Cleveland in 1917, and Austin and Jonas in 1917, acidosis was noted as a result of operation under anæsthesia.

Wright in his study of the toxæmia of gas gangrene observes a reduction of the alkalinity of the blood serum as determined by titration with acid to a certain end point, and he definitely recognizes the " acidæmia " as the cause of the shock-like symptoms of the patient suffering from this form of toxæmia.

Shortly after this, Cannon began an investigation at a casualty clearing station in France, and using van Slyke's method for measuring the alkali reserve of the plasma (plasma bicarbonate) he reported a notable deficiency of the alkali reserve in the blood of patients suffering from shock. His observations showed that the extent of the deficiency generally corresponded with the severity of the shock, and he recommended that the amount of the reduction of the alkali might be used as an index as to the fitness of the patient for operation.

The question now arose as to whether the acidosis, the existence of which in shock was beyond dispute, should be regarded as a determinant factor in the cycle of shock symptoms, an essential cause in other words, or whether it was merely a secondary result of a progressive circulatory deficiency. This important question has now been decided, and the results arrived at by the Shock Committee may be summarized as follows :—*

(*a*) Acidosis in the sense of a simple reduction of the bicarbonate of the blood plasma is not the cause of shock or an important factor in its production.

(*b*) Experimentally, in dogs it has been found that the pressure could be kept at 80 mm. for an hour without a reduction of the alkali reserve. Below 60 mm., however, a reduction always occurred. After a 20 per cent. hæmorrhage, a pressure of 80 mm. for an hour reduces the alkali reserve, *i.e.*, produces acidosis.

(*c*) A progressive uncompensated fall of the alkali reserve is the result of an inadequate oxygen supply to the tissues.

(*d*) Oxidation of the tissues is more easily rendered inadequate by defective circulation through the capillaries than by a reduction of the oxygen-carrying power of the blood, or of oxygen tension in the inspired air when the circulation is kept at an efficient level.

(*e*) The progressive uncompensated fall of the alkali reserve is a symptom of a deficient capillary circulation, and not a cause of such.

(*f*) To some extent, the rise of H-ion concentration (fall of the alkali reserve) must be regarded as a protective measure rather than harmful except in the terminal stage.

(*g*) The protective action comes into play through the stimulating effect on the bulbar centres, though it must be confessed that the protection has little value, for the depressed centres are incapable of a normal response.

Great importance must be attached to these observations and conclusions. They have a special bearing upon the question of treatment.

* Report No. 7 of the Committee.

Collateral Factors.—There still remain three other factors, which may be termed collateral factors. They are cold, hæmorrhage and sepsis. These three, collectively or individually, exert their influence in practically every case of shock. They act in a variety of ways. Cold is probably an important factor in effecting a delay in the capillary circulation, and when long continued it depresses all the body functions. Hæmorrhage rapidly leads to a fall in the blood pressure and all its associated deficiencies. Sepsis produces a fall in blood pressure, and by the circulation of toxines harmful effects are exercised on the body as a whole.

The essential underlying factor in the pathology of shock is a prolonged and progressive fall in blood pressure. The causes which may inaugurate the fall of blood pressure are various. Some are nervous, some clinical. Hæmorrhage and the absorption of toxic products from injured tissues are powerful collateral and sustaining factors.

With the establishment of a low blood pressure, something of the nature of a vicious circle comes into play, the prolonged hypotension leads to sub-oxygenation of the body tissues and a capillary stasis. The capillary stasis reduces the amount of circulating fluid and the sub-oxygenation of the tissues results in the appearance of various toxic products from imperfect tissue metabolism. All of these collectively further reduce the blood pressure and so the vicious circle goes on. It will continue to a fatal issue until some link in the chain is broken and the error of the blood pressure is overcome.

Diagnosis.

There are certain conditions which are allied to shock and so far resemble it as to cause possible confusion. It is important to make a differentiation as the treatment greatly varies.

The symptoms of hæmorrhage are apt to be confused with those of shock, and of course the two conditions are interdependent. But, while hæmorrhage cannot exist without some degree of shock, shock may exist without hæmorrhage. The history is generally sufficient to exclude or to suggest the possibility of hæmorrhage.

Acute anaphylaxis has been confused with shock. It may follow an injection of anti-tetanic serum, and it is generally recognizable by the urticarial manifestations and by the body œdema.

The toxæmia which results from the infection of a wound

with the organisms of gas gangrene may be mistaken for the development of shock. It is recognized by the local condition of the wound and by the period at which the symptoms appear.

Prognosis.

It is advantageous to have certain guides in estimating the chances of recovery of patients suffering from shock. The prognosis is grave when secondary shock appears early, when it rapidly deepens, when it is associated with the complications of hæmorrhage and sepsis, and when it is of the type associated with restlessness and severe respiratory disturbances. Failure of reaction to warmth and stimulation almost invariably means a fatal termination.

Treatment.

The treatment of the condition in its early stages has been dealt with in the previous chapter. The steps to be taken in dealing with a case when it arises at the casualty clearing station have now to be considered. It is also necessary that consideration should be given to the effects of operation on surgical shock and the means which are taken to combat them.

The first step should be to form an estimate of the degree of shock from which the patient is suffering. This estimate is important because upon it will depend the decision whether the patient is in a condition to stand immediate operation or whether he must first pass to a resuscitation ward for restorative treatment. The degree of shock may partly be judged by the patient's physical appearance or by his pulse rate, but these are deceptive, and the only sure method is to record his systolic blood pressure.

The question which naturally arises is: What level of systolic blood pressure is to be adopted as a safe minimum limit? The question is a difficult one to answer. The "threshold" point varies in different types of wounds. In perforating abdominal wounds, for example, there may be a considerable degree of shock with a high blood pressure.* If a definite standard is to be fixed, experience would seem to show that when the systolic blood pressure registers 90 mm. or less, restorative measures must be adopted before operative interference is begun.

In addition to recognizing that the man on admission is suffering from shock, care must be taken that the presence of one of the collateral factors, such as hæmorrhage or sepsis,

* See Report Medical Research Committee, No. II, Part I.

is not overlooked. In other words, it is bad judgment to concentrate one's energies on improving the shock condition of a man, while neglecting the fact that he is suffering from a gangrenous wound-infection, the toxic absorption from which is sufficient to counteract any benefit which the shock treatment might produce. It is essential that both complications be kept in view, and that while remedies are being adopted for the measure of shock which is present, the gangrenous wound is also receiving attention. Similar remarks may be applied to the question of hæmorrhage. It may appear unnecessary to draw attention to this detail, yet it is just such an axiom as this which is so often neglected in actual practice.

If it is decided that the wounded man on admission to the operation centre requires restorative treatment before any operative interference is carried out, he is segregated with similar cases in a resuscitation ward. In every operation centre, therefore, provision must be made for the establishment of such a ward. Its size will depend upon the amount of work which is likely to be met with. Its position should be central, and it ought to be in proximity to if not actually adjacent to the operating theatre; the reason for this is obvious. As far as is attainable in the exigencies of warfare, the ward and its surroundings should be as quiet as possible. The lighting of the interior should be good, for the operation of blood transfusion may require to be carried out, and the delicate technique associated with it requires the best possible illumination. Heating arrangements of some kind must be adopted so that a warm, uniform temperature is maintained.

The bedding arrangements are important. If actual beds can be provided, so much the better, but it may be impossible to provide these, and in many cases they are unnecessary. As the stay of each patient in the resuscitation ward is, comparatively speaking, short, sufficient to overcome the degree of shock, and as the occupants are therefore continually changing, it is sufficient if good stretchers on trestles are provided. The stretchers must be well supplied with blankets. Before they are occupied each may be warmed by placing a small oil stove beneath it. Well-protected hot-water bottles are placed at the foot of each stretcher, and when the patient is recumbent a protected hot-water bag should be placed over each groin.

For the convenience of transfusion arrangements, a sufficiency of small stands should be available.

In regard to the staffing of such a ward, at least two surgeons accustomed to this type of work are required; a sufficiency of nursing sisters of special experience must be provided, and the orderly work should be deputed to specially trained and picked men. It is impossible to exaggerate the importance of providing an efficient staff. Over-interference is to be avoided, and the special knowledge required can only be obtained by experience.

The patient is detained in the resuscitation ward until such time as his shock condition has improved sufficiently, and, as in estimating the original amount of shock, the best guarantee of improvement is to be obtained from the blood pressure.

When the patient is admitted to the resuscitation ward his wet and soiled clothing is removed, his body surface is thoroughly dried with a warm towel, and he is made as comfortable as possible in the accommodation provided for him.

From this point, the lines of treatment may be considered under the following headings.

Warmth.—All war experience goes to prove that after a serious injury the subsequent risk is greatly exaggerated by cold. Every effort must be made to keep the patient warm. In addition to blankets, bottles, and a stove beneath the stretcher, great advantages are derived from the use of electric heating apparatus. An efficient model of this kind is made by fastening several electric lights in the interior of a wire cradle. When the lamps are illuminated and the cage is covered with a blanket, an excellent hot-air chamber is provided.

Fluids.—There is complete agreement as to the value of administering plenty of fluid to these cases. It is, of course, best given by the mouth. Under certain conditions this method may be unsuitable, for example in abdominal wounds, when the administration will have to be made subcutaneously, or by the rectum. If the patient is able to take fluids by the mouth, the stimulating effects of tea and coffee may be taken advantage of. The administration of any fluid by the mouth is often made impossible because of the retching and vomiting which so frequently accompany shock, and in all such cases no time should be lost in giving rectal enemata or intravenous infusion.

On the supposition that in shock there is a reduction in the alkali reserve of the blood, it is urged that drachm doses of sodium bicarbonate should be given at intervals dissolved in tea, coffee or water. The fluids, too, should be well sweetened.

Sleep.—There can be no doubt regarding the wonderful restorative benefits of sleep. A natural sleep is of course the best, and therefore the patient should be kept in comfort and quietness and shaded from strong light.

In many cases sleep must be induced, and this is best accomplished by morphia. It is a debatable point to what extent the administration of morphia may be pushed. Crile advocates repeated doses until the respirations are reduced to twelve per minute, but it has been maintained that such reduced respirations increase acidosis. The concensus of opinion is in favour of administration of the drug to a point when pain and restlessness are relieved, and no further.

The fact must be kept in mind that with a rise in blood pressure a natural sleep often follows.

Drugs.—Adrenalin and strychnine, two former stand-bys in the treatment of shock, are now condemned as useless, and possibly dangerous.

Pituitary extract may produce a temporary benefit from its stimulating effect on the cardio-vascular system. There is no continued advantage from its use, and repetition of the drug is dangerous.

Alcohol has no real stimulating effect, and the only excuse for its administration is its use as a body food.

There are two drugs which are useful as temporary stimulants, namely, digitalis and camphor, given subcutaneously. They may be used with advantage when there is extreme collapse.

Transfusion.—The essential underlying fact in the development of shock is the fall in blood pressure. The various remedies which are used in the treatment of shock are directed towards a raising of the blood pressure, and naturally an intravenous infusion of fluid is the most rapid and effective method. The question then arises as to the type of fluid which should be used.

Intravenous normal saline has been for many years the fluid in most common use. It is now recognized that its beneficial effect is only transient. Its introduction intravenously in large quantities produces dilution and increase in the total volume of the blood; the kidneys, the skin and the lymph channels excrete the excess of fluid; there is profuse perspiration and presently the blood is actually less in bulk and more concentrated than before. Its benefit is therefore very temporary and eventually its use may do more harm than good.

Similar remarks apply to Ringer's solution and its various modifications.

Bayliss' gum-saline solution (6 per cent. gum acacia in 0·9 per cent. sodium chloride) is a fluid for intravenous injection which has proved of enormous value in practical use. In his most recent publications on the subject, Bayliss speaks of it as follows :—

"The most important factor in the treatment of wound shock is the ensuring of an adequate supply of blood, that is, of oxygen, to vital organs, especially to the nerve centres. This is most easily done by the intravenous injection of a 6 per cent. solution of gum acacia in 0·9 per cent. sodium chloride, in order to increase the volume of blood in circulation and to raise the arterial pressure."

The technique of transfusion and infusion is dealt with in the next chapter. It is only necessary to say that, to begin with, one pint of the solution should be given. It ought to be administered as early as possible after the injury if any sign of wound shock begins to appear. If only partial benefit is obtained in half an hour or so, a further injection may be made. It is wise to give the infusion slowly, fifteen minutes being required for the introduction of a pint. The solution should be warmed to blood heat.

Erlanger and Gasser advise the use of a 25 per cent. gum in 18 per cent. dextrin. This mixture results in a very viscid solution, and clinically the results have not been as good as those with Bayliss' solution.

In those cases of shock in which there has been the complicating factor of severe hæmorrhage, the transfusion of human blood gives excellent results. The method may be used in traumatic shock apart from hæmorrhage, but it is in the cases where there has been much bleeding that its results are most striking. The technique of its injection is dealt with in the next chapter, but it may be mentioned here that, in the opinion of most surgeons, experience showed that the citrate method was the safest and most reliable. A pint was the usual amount given for the first infusion.

Based upon the researches of Abel and Rous and Turner, a method has been used which consists in the injection of human blood corpuscles preserved in a citrate-dextrose solution. The solution may be preserved in ice for three weeks. The results obtained are in many cases as good as those obtained by using fresh blood.

Shock during Surgical Operations.

One of the most distressing features of work in an operative centre was the harmful influence which operative interference had upon men who were either already suffering from shock or were on the border line.

For example, a man is admitted in fair condition, and his chances of recovery seem promising. Some operative interference which involves the administration of an anæsthetic is necessary. During the anæsthesia or shortly afterwards the disastrous effects become apparent. There is profuse sweating, the pulse rate markedly increases, and also the respiration rate. Perhaps the most characteristic feature is the fall in blood pressure.

During the progress of the operation and while the patient is under the influence of the anæsthetic, a condition very closely resembling surgical shock has been induced. If the symptoms are severe, and in the absence of appropriate treatment, they may rapidly become fatal. There is restlessness, the pulse becomes uncountable and at the wrist imperceptible, the respiration rate continues to increase, and the blood pressure to fall. Death very rapidly ensues.

This might be the experience with a patient who was already in poor condition and in whom to some extent such an aggravation of symptoms was expected, but unfortunately the complication often appeared in those cases which at first seemed promising, and these were among the most bitter disappointments of surgical work.

It is obvious that during the course of the operation and of the anæsthesia, certain conditions are induced, or if already present, are aggravated to such an extent as to bring out this train of symptoms.

Examination before and after operation shows certain features. There is a lowering of the systolic blood pressure—and it may be taken as a working rule that the seriousness of the patient's condition is in relation to the degree of the fall; the greater the fall in blood pressure, the more acute the patient's condition. The blood examined with the hæmatocrit may show some degree of concentration at the end of operation, and it is likely that, in relation to a loss of fluid by sweating, there is a relative proportional increase of the solid constituents of the blood. Examination of the blood by van Slyke's apparatus before and after operation shows a reduction of alkali.

While these are the most striking demonstrable factors there are certain related conditions, each of which plays some part in forming the ultimate clinical picture.

The first of these is the man's general condition before operation. A patient who is weakened by exposure, by hæmorrhage and by sepsis, is peculiarly liable to what may be termed operative shock.

The second influencing feature is the extent and duration of the operation. A long operation and one associated with much traumatism is unpromising. An operation for multiple wounds, each wound perhaps slight in itself, often has a disastrous cumulative effect.

A third, and an exceedingly important factor, is the influence of the anæsthetic. The contra-indications of the use of chloroform in septic cases have long been known, and experience in war surgery confirms this observation. Ether, while less deleterious than chloroform, has, nevertheless, a bad effect.

Cannon has repeatedly shown the marked increase of acidosis which often occurs after even a short ether anæsthesia. With gas and oxygen anæsthesia these deleterious effects are very greatly reduced, if not averted, and, in addition, as no after-sickness is caused, the patient is not exhausted by constant vomiting and is also able to take the fluid nourishment of which he is in great need.

Preventive Measures.—These may be very simply summarized :—

1. If possible, operation on a case which shows persistent low blood pressure should be delayed until means have been taken to raise the blood pressure.

2. The operative procedure should be as short as possible, consistent with thoroughness.

3. The operation should be carried out with the least possible interference and trauma. Every effort should be made to avoid unnecessary loss of blood.

4. "Chilling" of the patient before, during or after the operation must be avoided.

5. If it is possible to exercise a choice of anæsthetic, that choice ought always to be given to nitrous oxide and oxygen.

6. If simple restorative measures have failed to raise the blood pressure before operation, it ought to be raised artificially by the intravenous infusion of human blood, or of one pint or more of 6 per cent. gum acacia solution in normal saline.

7. If examination of the blood shows that a condition of acidosis is present before operation, a reserve of alkali should be built up by the intravenous infusion of 1 pint of 4 per cent. solution of sodium bicarbonate.

When a condition of operative shock has been definitely established, means must be attempted to counteract it, but these measures are less satisfactory than preventive treatment and therefore every effort should be made to adopt preventive measures.

After the operation, the patient must be kept thoroughly warm. If the conditions are suitable, quantities of alkaline fluid are given by the mouth, and there are advantages in combining sugar in the shape of glucose with the alkali. The giving of alkalis by the mouth in this way will often counteract a developing acidosis.

If these measures are failing and the shock condition is deepening, resource should be had to intravenous infusions. If there is evidence of an acidosis being present, and quickening of the respiration rate is extremely suggestive of such, the 4 per cent. sodium bicarbonate solution should be infused to the amount of one pint. If there has been an associated loss of blood, an effort should be made to restore its volume by the transfusion of human blood, or by the infusion of the colloidal solution of gum acacia.

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CHAPTER V.

BLOOD TRANSFUSION.

THE history of blood transfusion dates back many centuries, but it is due to the efforts of American surgeons and physicians that interest in it has been reawakened and that it has been established as a definite therapeutic procedure. The direct anastomosis of artery and vein by Carrel and the introduction of Crile's cannulæ were followed by other modifications, such as the interposition by Brewer of a paraffined glass tube between the donor's artery and the recipient's vein, and Edward Lindeman revived the syringe method, first reported in 1892 by Von Ziemssen, and placed it on a basis of efficiency.

Although Sir Berkeley Moynihan has employed blood transfusion since 1908, nevertheless the procedure was not practised by the majority of the surgeons of Great Britain until the war provided them with unparalleled opportunities for its employment in their endeavour to deal effectively with the problem of saving the lives of the severely wounded men, who were daily reaching the field ambulances and casualty clearing stations.

The direct method of blood transfusion in the hands of the surgeons on the British front received an impetus from the employment of the Fullerton-Dreyer-Bazett paraffined cannulæ and rubber tubing at the Boulogne Base in the latter half of 1916, and from its advocacy in a paper embodying their experiences published in 1917. These cannulæ and tubing found their way into the forward area, and some use of the apparatus was made in the casualty clearing stations.

In 1916 and 1917 the Canadian surgeons practised and popularized the indirect method of blood transfusion ; Archibald in September 1916 pointed out the easy technique of the citrate method, and Bruce Robertson, both in his papers and in practice in the Second Army area, established the claims of the syringe-cannula method as a valuable therapeutic procedure. In 1917 the paraffined glass tube of Kimpton-Brown was brought to the British hospitals by the Americans, and American surgical teams from the base introduced the method to the forward area ; Crile, Crabtree, Cabot and Alton were amongst those who popularized this method in the Second Army area.

The use of preserved blood was introduced into France by Captain Oswald Robertson, U.S.A., and brought by him to the Third Army in November 1917.

In 1917 and 1918 the practice of blood transfusion was carried still further forward than the casualty clearing station zone, largely owing to the efforts of Kenneth Walker in the Third Army, of Guiou amongst the Canadians, and of Holmes-à-Court amongst the Australians. Resuscitation teams were trained in transfusion methods from amongst the medical officers attached to the ambulances in special "shock centres" and in certain casualty clearing stations.

Blood Donors.

It is well known that the serum of one animal species may agglutinate or hæmolyse the red blood cells of another species, and it is also true that this same phenomenon may occur within a species; thus the serum of one person may agglutinate the corpuscles of another person and, less frequently, may hæmolyse them. Such reactions are known as iso-agglutination and iso-hæmolysis.

Moss found that all individuals fall into four groups as regards the hæmolytic and agglutinative properties of their blood, and he constructed a table depicting the agglutinative reactions between the four groups.

Moss's Table.

Serum of Groups.	*Cells of Group.*			
	I.	II.	III.	IV.
I.	0	0	0	0
II.	+	0	+	0
III.	+	+	0	0
IV	+	+	+	0

This table is based on the agglutinative reaction, since this always precedes hæmolysis, and is a much simpler test.

The group of any individual is rarely established at birth, but usually becomes fixed within the first few months of life. Apparently, once the group is established it does not alter.

It is therefore important, in order to make transfusion a safe procedure, that the surgeon should determine beforehand the reaction of the recipient's blood towards that of the prospective donor. Where it is possible, it would appear to be wise to select a donor from the same iso-agglutinin group as that to which the recipient belongs, but Roger Lee has shown that this is by no means necessary and that the only practical consid-

eration is that the serum of the recipient does not agglutinate the red cells of the donor. He therefore suggests that a group IV donor be used where it is impossible to get a donor of the same group as the recipient, and he bases this suggestion on the fact that group IV corpuscles are not agglutinated or hæmolysed by the serum of any individual of any group. He designates members of the group IV as " universal donors," since they may be used for patients belonging to any of the four groups. Similarly he designates members of the group I as " universal recipients," inasmuch as they can receive blood from members of any of the other groups without any untoward reaction appearing.

It is true that this precaution was not always taken in the earlier blood transfusions of the war ; thus Bruce Robertson's series consisted of ungrouped transfusions, and the report of 220 cases of transfusions by the staff of the Lakeside Unit, No. 9 General Hospital, also shows that unmatched blood was used in 216 cases. In the majority of these 216 unmatched transfusions no sign of incompatibility was observed, but in nearly 25 per cent. chilly sensations were experienced, and in one case a sharp reaction resulted in death. It appeared to some surgeons that soldiers who received transfusions in the advanced medical units, before systematic arrangements had been established for testing donors, showed fewer reactions than those transfused under similar conditions at the base. The question naturally arises whether or not the presence of disease, *e.g.*, suppurative processes, etc., influences the amount of agglutinin present in the recipient's serum.

In cases of extreme urgency where no means exist of grouping the donor and recipient, a preliminary injection of 15 to 20 c.c. may be made in a tentative fashion into the recipient's circulation, and if no symptoms occur within one to two minutes, the bloods may be regarded as sufficiently compatible and the transfusion then proceeded with.

Symptoms of incompatibility which are most frequently seen are in order as follows :—

(1) Pain in the lumbar region ; but Cabot has noted this pain even when no untoward events have followed the transfusion.

(2) Inspiratory dyspnœa.

(3) Urticaria appearing at once and of a characteristic biuret colour ; it bursts out on face, chest and abdomen.

(4) Digestive disturbances, *e.g.*, vomiting and purging, in about 30 seconds.
(5) Ordinary symptoms of shock, *e.g.*, dilation of pupils, sweating and restlessness.
(6) Late symptoms and signs, *e.g.*, jaundice, hæmaturia, and hæmorrhages from mucous membranes.

Any of these first five may appear in 30 seconds.

It is hardly necessary to state that syphilitic or malarial patients must be rejected as prospective blood donors, as also those suffering from such other infective diseases as trench fever.

The following constituted the majority of blood donors—lightly wounded men, dental patients and men suffering from sprains, flat feet, and minor injuries. No difficulty was ever found in procuring blood donors: up to the middle of 1918 the spirit of comradeship among the troops gave a plentiful supply of donors, and later an order enjoining three weeks' leave in England for blood donors made it popular with lightly wounded men.

To determine the blood group of any individual, it is enough to test his corpuscles against the known sera of groups II and III. This is readily effected as follows; a drop of group II and one of group III serum are placed on a clean glass slide; a small drop of the blood to be tested is then transferred to each of these drops of serum with a glass rod. The red cells make a uniform suspension in the citrated serum. If there is no agglutination, the suspension persists; whereas if agglutination takes place it usually appears in less than a minute in the form of masses of agglutinated cells easily discernible to the naked eye. The drop on the slide assumes a "sandy" appearance (Fig. 1).

Methods of Blood Transfusion.

The following methods of blood transfusion have been adopted:—

Transfusion of unmodified or whole blood.
(1) Direct transfusion (artery to vein anastomosis).
(2) Indirect transfusion,
(*a*) paraffin tube,
(*b*) syringe methods.

Transfusion of blood altered by anti-coagulents.
Citrated blood transfusion.

Transfusion with preserved blood cells.

ILLUSTRATION OF MACROSCOPIC AGGLUTINATION TEST.

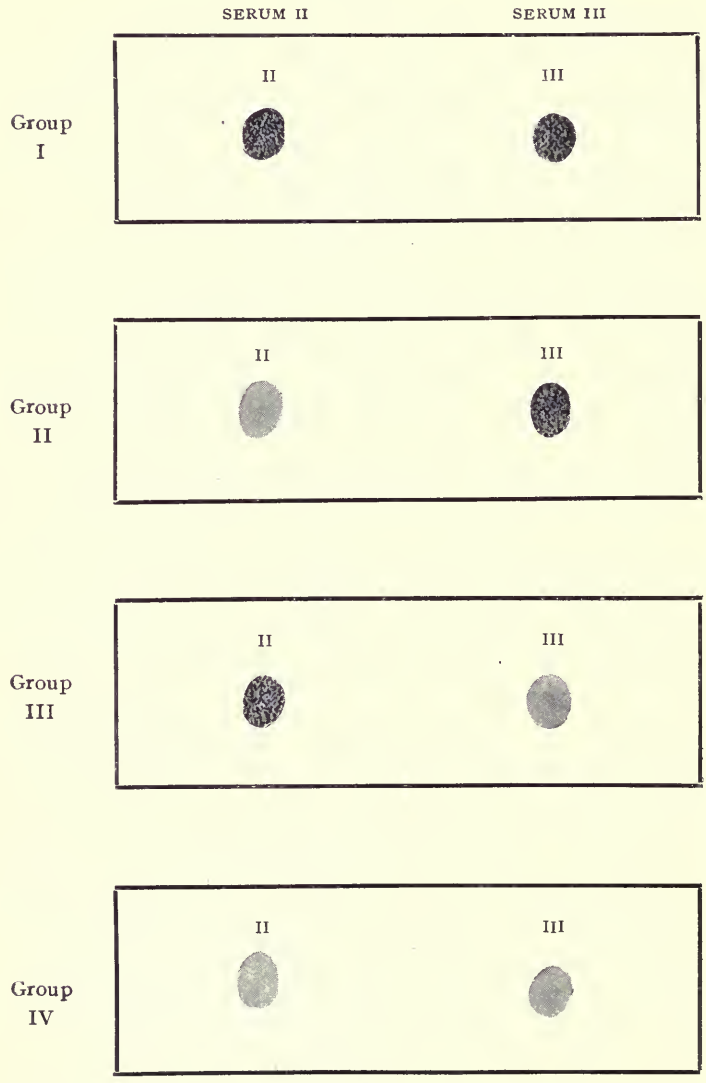

Fig. 1.

Direct Blood Transfusion.—The apparatus consists of two glass or silver cannulæ connected by a length of about 7 inches of rubber tubing, the dimensions of the cannulæ being : arterial cannula length 4 cm., external diameter 2 mm. at point, venous cannula length 4 cm., external diameter 3 mm. at point. The silver cannulæ are the most useful, and have a bulbous end to ensure their retention in the vessels without the necessity of tying or holding them in place.

Thin-walled transparent rubber tubing, which will stand heat and which will allow pulsation to be easily felt during the operation, is used. The tubing is coated with a mixture of hard and soft paraffin, setting between 43° C. and 48° C.

The donor and recipient are placed on beds or tables at a suitable distance apart with a small table or board between so that the limbs may be placed in position ; the limbs lie parallel and as close together as convenient. The radial artery of the donor is exposed and one of the superficial veins in front of the elbow or the internal saphenous vein is dissected out in the recipient. These are ligatured at the distal limits of their exposure, and a light bull-dog forceps or Crile's clamp is placed at the proximal end of each. Each vessel is opened by a V-shaped incision with a very small and sharp pair of scissors, and the flap made by this incision is seized with mosquito forceps. The smaller arterial cannula is first introduced into the artery, and the bull-dog forceps released for a moment to permit the apparatus to fill with blood and expel air ; the forceps are then replaced. The larger cannula is introduced into the vein, and the bull-dog forceps on both artery and vein are now released, and the blood is allowed to flow. Great care must be taken to avoid handling the vessels roughly during the exposure, since this may produce spasmodic contraction and difficulty in the introduction of the cannulæ ; undue traumatism also favours coagulation.

The amount of blood is regulated by the conditions of the donor and the recipient ; the onset of anæmic symptoms in the donor indicates that he has lost as much blood as he can conveniently afford ; in a man of average weight these symptoms will arise when he has lost about 1,000 c.c.

It has been claimed for the method that the transfusion is conducted under conditions as near the physiological ideal as possible, but there are many disadvantages in its employment both in military and civil surgery, and it has been entirely replaced by the indirect and the citrate methods. The more important drawbacks are, first, the inability to gauge the

amount of blood transfused ; secondly, the elaborate technique required ; thirdly, the difficulty of applying it in the front areas, and in hospitals in times of active military operations with many casualties ; and fourthly, a certain degree of risk of sepsis to the donor.

Indirect Transfusion Method.—Transfusion of whole blood is very simply performed by means of the paraffined glass tube method (Fig 2). The Kimpton tube, or some modification thereof, *e.g.*, the " No. 17 " tube, so called because first used in

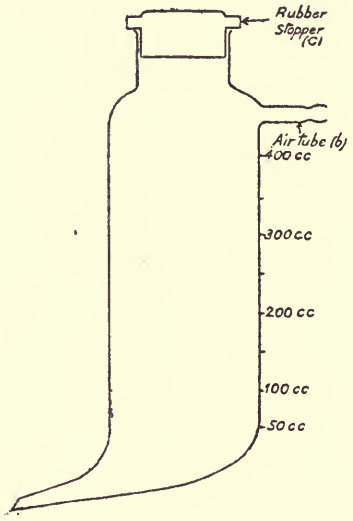

Fig. 2.

No. 17 Casualty Clearing Station, is the most convenient type of receptacle, and the greatest care must be taken that the coating of the vessel is done under rigidly aseptic conditions. To clean new-blood transfusion tubes, they should be washed with hot water containing an ether-soap solution, the interior of the receptacle being swabbed with gauze on a long instrument. They should then be rinsed with hot water.

To clean paraffined tubes after use, as more or less blood will adhere to the paraffin coating on the inner surface of the tubes, they should be rinsed vigorously with cold water ; then filled half-full with boiling water and some ether-soap solution, and shaken. If necessary, friction with gauze on a long instrument will erase any small patches of blood remaining. The tube should be rinsed again in hot water. It is then ready for sterilisation.

Blood transfusion tubes may be sterilised either by boiling or in an autoclave. If by the former method, the tube should be boiled for twenty minutes, and then dried before being paraffined. If sterilised in an autoclave, the cork must be removed from the tube, and the tube and the cork wrapped in cotton wool and then in a towel fastened with a safety-pin before being placed in the autoclave.

To dry blood-transfusion tubes the operator's hands are "gloved." A sterile towel is placed on the table. The pins are removed from the towel by an attendant, who also unwraps the towel sufficiently to expose the cotton-wool. The tube is removed from the cotton-wool, the latter remaining spread out on the towel which surrounded it. Into the tube half an ounce of alcohol is poured; the neck and cannula of the tube are closed with gloved fingers, and the vessel is shaken. The alcohol is then poured out allowing a small amount to flow through the cannula. Next, an assistant pours into the tube half an ounce of ether, and the tube is shaken vigorously. It is now ready to be paraffined.

To coat the tube with paraffin there are two methods.

In the first method a small dish of paraffin (melting-point 45°–55°C.), which has been previously sterilized in an autoclave, is brought to the boiling point over a flame. The cork is then inserted tightly in the neck of the tube. A sterile piece of rubber tubing is attached to the glass tube inserted in the cork. The vessel is held over the flame and rotated so that all parts of it are heated. The cannula of the transfusion tube is inserted into the heated paraffin, the free end of the rubber tube (8 inches long) placed in the operator's mouth, and about three ounces of paraffin drawn up into the receptacle. The rubber tubing is then detached from the receptacle and, with a finger over the cannula, the tube is shaken. The excess of paraffin is allowed to escape. The tube is then so held that the cannula is pointing up, thus permitting the excess of paraffin in the cannula to flow back into the tube. It is held in this position until hardened. Striking the outer surface of the container with gauze soaked in alcohol will hasten the cooling process. The tube is then ready for use.

In the second or *Alton's method* the tube is dried as noted above. Two drachms of a paraffin-ether solution (1 part of paraffin in 80 parts of ether) are poured into the container. The tube is then rapidly shaken so that the entire surface is bathed in the solution. The excess solution is now poured out through the neck of the tube. The ether evaporates quickly,

and should leave a thin smooth coating of paraffin on the interior of the tube. The vessel should be left on a sterile towel with the cannula pointing upwards, until the excess of the paraffin-ether solution flows back from the cannula into the tube. The paraffin which accumulates at the neck of the tube should be removed by a piece of gauze placed over a gloved index-finger, so as to ensure a more accurate fit of the cork. The cork is only placed in the tube when the latter is about to be used.

The operation of indirect transfusion is performed as follows. Under local anæsthesia, the veins of the donor and of the recipient are exposed at the elbow. The vein of the donor is ligatured proximally to the proposed site of the opening. A strand of catgut or linen thread is passed under the vein distally to the proposed opening but not tied. The weight of an attached pair of artery forceps will have the effect of kinking the vein at this spot, and will enable the opening into the vein to be made bloodlessly. The vein is now opened and a " mosquito " forceps applied to each lip of the incision in it.

The vein of the recipient is treated in like manner, but the ligature is tied distally to the selected site of the incision in the vein, and a strand of the ligature is neatly passed under the vein proximally to this point, and not knotted. A " mosquito " forceps is applied as in the donor's vein. The cannula of the paraffin tube is introduced into the donor's vein, pointing distally. Congestion of the veins by a rubber band of suitable tightness, and alternate movements of clenching and relaxing the fingers, will accelerate the flow of blood into the paraffin tube.

The tube is filled, carried to the recipient, and the tip is introduced into his vein. The cannula is directed proximally. Hand bellows are applied to the glass tube in the cork of the container, and blood is slowly pumped thereby into the recipient. Care is necessary not to pump the blood in too quickly, for if this is done the right side of the heart may be dilated. At least ten minutes should be taken to introduce a pint of blood. A second paraffin tube should be used in the event of more blood being required from the donor. The ligatures are now tied and cut short, and the intervening segment of vein excised. The wounds of donor and recipient are closed by suture.

Another method, the syringe cannula method, gave excellent results in the hands of Bruce Robertson at No. 2 Canadian Casualty Clearing Station. Eight or ten 20 c.c. " record "

syringes are required; a cannula is introduced into the recipient's vein and one into the donor's vein. Bruce Robertson attaches a short piece of rubber tubing to each. By means of the record syringes worked in series, blood is withdrawn from the donor's cannula and injected into that of the recipient. Between the successive withdrawals or injections of blood in donor and recipient respectively a small amount of normal saline is forced through the cannula to clear it of blood and to prevent clotting. The syringes and cannulæ at the commencement may be lubricated by drawing sterile liquid paraffin through them.

Two operators are required to transfer the blood, and a nurse, assistant or orderly is necessary to flush each syringe with saline before it is used again. As much as 1,000 c.c. or more of blood may be given in this way.

The main advantage of the method is that theoretically the blood is transferred before it has time to undergo any appreciable change outside the body. It is said, however, that reactions occur in about ten per cent. of transfusions by this method, a percentage somewhat greater than is the case with blood transfusions performed by means of the paraffin tube.

Citrated Blood Transfusion. — Although this method of transfusion is very simple, certain precautions must be taken in order to avoid unnecessary damage to the blood corpuscles and the toxic effects liable to follow such injury. The apparent simplicity of transfusion with citrated blood has undoubtedly led in certain cases to a lack of appreciation of the care necessary in carrying out the technique, and consequently undesirable after-effects have resulted. The important points of the technique are described later on.

The apparatus shown in Fig. 3 was designed and introduced into France in 1917 by Captain Oswald Robertson, U.S.A. It is simple in use, and can be made from material easily obtainable. It consists of the following parts :—

A wide-mouthed, well-cleaned dry bottle of 900 to 1,000 c.c. capacity will serve as the transfusion bottle. Four marks are made on the bottle with a file, one at 160 c.c., indicating the level of the citrate solution, the others at 660 c.c., 760 c.c. and 860 c.c., indicating 500, 600 and 700 c.c. of blood respectively. Then 160 c.c. of a 3·8 per cent. solution of sodium citrate (isotonic), made up with freshly distilled water and filtered, is placed in the bottle which is stoppered with a cotton wool plug wrapped in gauze. The bottle is then

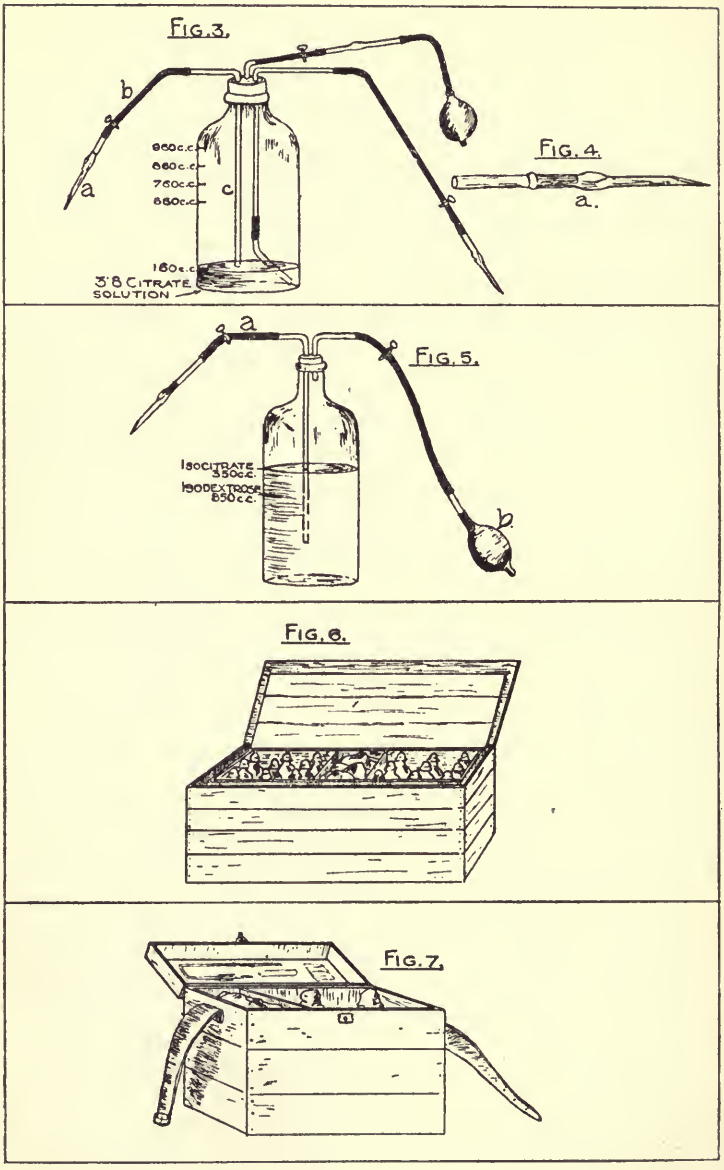
FIG. 3.
b
a
c
960c.c.
860c.c.
760c.c.
660c.c.
160c.c.
3·8 CITRATE SOLUTION
FIG. 4.
a.
a
FIG. 5.
ISOCITRATE 350c.c.
ISODEXTROSE 850c.c.
b
FIG. 6.
FIG. 7.

autoclaved for half an hour at 100° C. When a number of transfusions are being done, half a dozen or more of these bottles should be sterilized at a time and kept ready for use.

For obtaining the blood from the donor, the needle must be of large bore, 1·5 to 2 mm. internal diameter, and not more than 3·5 cm. long. Its inner surface must be well polished and kept scrupulously clean. When not in use the point must be protected by a piece of rubber tubing, and the cutting edge kept continually sharp. The needle is the most important part of the apparatus, and most of the failures in the use of the citrated method of blood transfusion can be traced to the use of an unsuitable, a blunt, or an imperfectly clean needle. A good type of needle with rubber tube and glass connecting piece attached is shown in Fig. 4. The rubber connection should be flexible and not more than 10 cm. long. The inner surface should be smooth as in the case of all other surfaces with which the blood comes in contact. The glass inlet tube is made of a large bore glass (6 mm. internal diameter) and should extend below the level of the citrate solution.

The needle employed for giving the blood is less than that employed for obtaining it, since the danger of blockage through clotting is greatly diminished. The needle is attached, as in the former case, by means of a small glass connecting piece, the free end of which is thrust into the end of a long rubber tube after the needle is in the vein. The glass tube is bent so that the end projects into the lowest part of the bottle. In this way almost every drop of blood in the bottle may be given. The bulb of an enema syringe can be made to serve as a pump, with the valves arranged as in Fig. 3. Suction or pressure can be made by reversing the ends.

The procedure is as follows. The donor's arm is extended at right angles to the body; the skin of the antecubital space is scrubbed with soap and water and the sterilization completed with alcohol. A tourniquet is lightly applied high up and as large a vein as possible selected. The pain of the puncture may be avoided by the preliminary injection of a drop of novocaine solution, an amount which is insufficient to obscure the underlying vein.

A small nick is made in the skin over the anæsthetized spot with the point of a scalpel and the needle inserted for a short distance beneath the skin before it enters the vein. When the flow of the blood from the needle makes it certain that the latter is within the lumen of the vein, the needle is

connected to the intake tube by means of the glass connecting piece. Previous to puncturing the vein, the operator has assured himself that the transfusion bottle is ready and that the intake tube is full of citrate solution in order to diminish the chances of coagulation. A moderate degree of negative pressure has also been obtained by means of the pump, so that the connecting up and the removal of the pinch cock are immediately followed by a flow of blood into the bottle.

A moderate degree of suction is maintained and the flow of blood is encouraged by removal of the tourniquet and by instructing the donor to open and close his hand throughout the operation. It is essential to keep the needle immobile, and the operator should allow nothing to distract his attention from this all-important point. Should the blood cease to flow because of displacement of the needle or of clotting within its lumen, the needle must be withdrawn and the operation repeated, but with a fresh needle and another vein. Throughout the whole proceeding the transfusion bottle is given a gentle rotary movement in order to ensure thorough mixing of the blood with the citrate solution. Failure to ensure this often results in the formation of a large clot at the bottom of the bottle.

When the blood has reached the desired amount (500 c.c. to 700 c.c.) the pinch cock is closed and the needle withdrawn. The pump is then reversed and the bottle placed in a glass jar containing water at body heat so as to maintain the temperature of the blood. It will be noted that a column of blood is left in the intake tube after the bleeding has stopped; this is done in order to avoid drawing into the bottle any little clumps of fibrin which may have begun to form immediately after the blood has ceased to flow through the tube.

If the donor's veins are small and the needle method fails, the vein may be cut down upon and the cannula thus inserted; this, however, is a more formidable and time-consuming procedure than mere puncture, and it should seldom be necessary.

The recipient's arm is prepared in a manner similar to that described for the donor. A smaller-sized needle is, however, used for the giving of the blood, and usually it is unnecessary to anæsthetize the skin. Before exerting positive pressure on the citrated blood in the bottle it is well to prevent the possibility of the rubber cork being forced out by securing it to the bottle neck by means of two narrow strips of plaster. Any air in the outlet tube is expelled by opening for a moment

the pinch cock and thus allowing a small amount of blood to escape. When the needle is properly in position within the lumen of the recipient's vein, it is connected to the outlet tube and the pinch cock removed. A small amount at positive pressure is maintained by means of the pump, and a slow flow of blood into the veins of the recipient secured. Forcing the blood into the patient at a high pressure and with great speed must be avoided since it is liable to produce untoward symptoms and dilatation of the right side of the heart. Ten minutes should be the minimum time for the introduction of 500 c.c. of blood. The stopcock must be closed before an air bubble begins to pass up the tube.

Coating the inside of the tubes and bottle with paraffin is unnecessary, provided that care has been taken to ensure that the inner surface is smooth and scrupulously clean.

An isotonic solution of sodium citrate is employed in preference to a 10 per cent. solution, since less damage is thereby likely to be inflicted on the delicate blood corpuscles. No harmful effects are produced by the amount of citrate employed in the above method, although in some cases a mild rigor may occur.

Although it is better to use blood freshly withdrawn, it has been found safe to administer citrated blood taken as long as 18 hours previously from the donor's veins. It is a great advantage to be able to prepare for the arrival of a large number of wounded by drawing off beforehand a certain quantity of blood and having it ready in case of need. Until the blood is actually required the bottles are kept in as cool a place as possible in order to diminish the chances of hæmolysis. This plan of preparing beforehand bottles of citrated blood ready for use was carried out with great success during the heavy fighting in the summer and autumn of 1918.

Although it is desirable to employ such a method as the above when proper facilities exist, it is nevertheless worth remembering that in cases of need transfusion can be performed in the absence of all such special apparatus. All that is required for collecting the blood from the donor is a needle of large calibre or a glass cannula to which a small length of rubber tubing is attached. The blood is led into a sterilized bowl containing a solution of sodium citrate or normal saline, admixture with the solution being ensured by gently stirring with a sterilized glass rod. The diluted blood is given like an ordinary saline infusion through a funnel and cannula after filtering through two thicknesses of gauze.

Transfusion with Preserved Blood.—It was felt that if blood could be drawn off from donors during times of inactivity and stored ready for use during "rush" periods, one of the disadvantages of transfusion, namely the time absorbed in its performance, would be obviated. The giving of blood would then make no more demand on the overworked surgical staff than the giving of a saline infusion, and a greater number of wounded men could thus be given the benefit of transfusion than was possible under other conditions. The experimental basis for this work was laid by Rous and Turner of the Rockefeller Institute, who found that blood when received into a solution of dextrose and sodium citrate and kept cold could be preserved for several weeks. The application of this principle to war conditions was accordingly tested by Captain Robertson at a casualty clearing station in the Third Army during the battle of Cambrai in November 1917. The following is a brief summary of the technique employed in preserving blood.*

The solutions of dextrose and sodium citrate are made up on a basis of 500 c.c. of blood, this being the usual amount taken from the donor. This requires roughly 350 c.c. of isotonic sodium citrate (3·8 per cent) and 850 c.c. of 5·4 per cent. dextrose solution. These two solutions are made up with freshly distilled water, and autoclaved separately. Special care must be exercised to sterilise the dextrose solution effectively, as otherwise moulds are liable to give trouble.

The apparatus for bleeding is shown in Fig. 5. Owing to the considerable bulk of the preserving fluid, a large bottle such as a Winchester flask is required. If this bottle has been employed for the sterilizing of the dextrose solution, all that is now required is to add the 350 c.c. of isotonic citrate, and to insert the cork which bears the suction apparatus and intake tube.

The operation of withdrawing the blood is similar to that already described under the citrate method of transfusion. The intake tube is first filled with solution by increasing the pressure within the transfusion bottle and then closing the stop cock. The pump is then reversed and a negative pressure obtained. The transfusion needle is inserted into the donor's vein and the clip on the intake tube removed. Blood is drawn into the bottle and mixed with the preserving fluid. Owing to the larger quantity of diluting fluid present, it is unnecessary to agitate the bottle until after the bleeding has stopped, for clotting is extremely unlikely to take place.

* For fuller details *see* B.M.J., June 22nd, 1918.

An ice-box is necessary for storing the blood (Fig 6). A suitable one can be improvised out of two packing cases of such dimensions that, when one is placed within the other, an air space of two to three inches breadth is left between the two boxes. This space is filled with sawdust or some other non-conductive material. A tight-fitting door or lid is necessary.

It is well to line the inside box with tin, and one end of this space should be partitioned off for the reception of ice. To ensure an equable temperature, a small dug-out may be excavated for the reception of the box.

At the end of five or six days the blood which was previously uniformly mixed with the preserving fluid will be found to have settled to the bottom of the bottle. When it is required for use, the superfluous supernatant fluid is syphoned off, leaving the blood corpuscles and only as much of the fluid as will make up, with them, the original volume of the blood. The presence of hæmolysis may be suspected if the preserving fluid above the corpuscles is pink in colour instead of presenting a bluish-white or yellowish appearance. Hæmolysis generally indicates contamination, and such blood should of course be discarded. When no hæmolysis has occurred the cultures of the supernatant fluid have invariably proved negative.

In the procedure for transfusion of preserved corpuscles the fluid containing the preserved corpuscles is brought to body temperature by standing the containing bottle in warm water. It may then be given to the recipient by means of a bottle similar to that described under the heading of transfusion of citrated blood, or even more simply, in the same way as an ordinary saline infusion, by means of a funnel and tube. Filtering the suspension through two layers of sterile gauze before use is advisable, since small clumps of corpuscles occasionally form during the course of sedimentation. Blood preserved in this manner has been given at any period up to 26 days, and according to Captain Robertson equally good results were obtained by this method as by the use of fresh blood transfusions. The method was not generally adopted because of the greater simplicity of other techniques.

In the hands of Kenneth Walker, however, it proved of great use at aid posts or advanced dressing stations, although a preference is still maintained for fresh blood. No ill effects have been observed from its employment except in one desperate case where, no other blood being available, corpuscles which were under suspicion of hæmolysis were administered as a last resource. In order to test the capacity of preserved

corpuscles to withstand the trauma resulting from transportation, Captain Walker carried with him a bottle of preserved corpuscles during a journey from Arras to London. In spite of the shaking inevitable in such a journey, the corpuscles arrived in good condition and showed no signs of hæmolysis.

Comparative Advantages of the Citrate and the Whole-blood Methods of Transfusion.

The respective merits of the above two methods of performing transfusion have long been under discussion. For each certain advantages are claimed. Supporters of the whole-blood method claim that by avoiding the use of an anti-coagulant, and by relying simply on the coating of the tube with paraffin to prevent clotting, the blood is administered in an entirely normal condition, free from admixture with drugs. But whilst it must be admitted that this administration of pure blood, which approximates as nearly as possible to that circulating within the blood vessels, is the ideal to aim at, nevertheless it cannot be said that the whole-blood method of transfusion could, in the experience of workers in France, claim results appreciably better than those obtained by other methods. Reactions which could be fairly attributed to the use of citrate were mild in character, and no accident of a serious nature was recorded. Not infrequently transfusion with citrated blood was followed by a rigor which lasted for a few minutes, and which apparently left no ill effects in its train. In the opinion of some observers, the return of colour to the lips and the improvement in the patient's condition were more immediate and more dramatic after transfusion with whole blood than after the use of citrated blood; otherwise the results yielded by the methods appeared to be much the same.

Whatever may be the respective merits of these modes of performing transfusion under conditions of civil surgery, it is undeniable that the range of utility of the citrate method is greater than that of the whole-blood method under war conditions. The citrate method was frequently employed amid surroundings which would have rendered the whole-blood method impossible. Not only was the former method more easily carried out, but it also permitted the transport of the blood from the donor to the recipient without any necessity for the two being side by side; blood could be extracted from a donor in a separate tent whilst an operation was in progress, and could thence be transported to the operation tent for administration. No interruption of the operation in

progress, and no congestion of an already overcrowded operating tent were thereby necessitated. A skilled transfuser, by devoting himself entirely to the task of drawing and citrating the blood, could supply sufficient for a dozen cases, leaving to the anæsthetists in the operating tent the simple task of the administration of the blood. Moreover, as has already been pointed out, a certain supply of blood could by means of the citrate method be prepared ready for use a few hours previous to the arrival of the wounded, thereby saving time when the demand for transfusion became excessive.

For these reasons, although during times of moderate pressure of work and in a well-equipped hospital the whole-blood method may be most usefully employed, under war conditions the citrate has a decided superiority over other methods of transfusion, and after experience on the British front the Americans selected this as the method to be practised in their own divisional areas.

Organisation for Transfusion at a Casualty Clearing Station.

Although no special arrangements are required during periods of ordinary activity, much can be done to facilitate transfusion at the clearing stations during rush periods. To a resuscitation team should be delegated the duty of collaborating with the surgeon by relieving him of the work of looking after bad cases requiring the employment of special resuscitation measures either before or after operation. The officer chosen for this duty should be expert in the technique of transfusion, and should have charge of the pre-operation ward devoted to bad cases. Under him was a resuscitation team of sisters and orderlies experienced in the work and possessed of enthusiasm for dealing with desperate cases. When it was necessary to cope with a large number of transfusions and the citrate method was employed, the transfusion officer devoted himself entirely to the work of drawing blood, the administration of the blood being left to the anæsthetists or to any other officer who might be available.

When previous warning had been received of the arrival of large numbers of wounded, much could be done to facilitate the work by the preparation of preserved blood according to the method previously described. This supply could be used later on for cases of an extremely urgent nature when the loss of an extra ten minutes might be fatal, or else for supplementing freshly drawn blood when the demand had exceeded the supply.

The two or three hours which preceded the arrival of the wounded were utilized by the resuscitation officer in preparing blood by the citrate method, so that a certain number of bottles were ready when the rush began. If kept in a cool place blood drawn off in this way could be kept at least ten or twelve hours without danger of hæmolysis.

It must be remembered that if the best results are to be obtained from transfusion, careful attention must be paid to the ancillary methods of treatment, such as rest and warmth. Most important amongst these supplementary methods is that of making good the great loss of fluid from which the wounded man is suffering. When vomiting is no obstacle, repeated drinks should be given, a special orderly being employed to encourage the patients in the resuscitation ward to drink. When repeated vomiting makes this impossible, reliance must be placed on rectal salines, or in cases of urgency on intravenous injection of 6 per cent. gum solution. It is not uncommon to find that the full benefit from transfusion is obtained only when the blood has been followed up by the injection of 500 to 800 c.c. of saline or gum solution.

Transfusion in the Divisional Area.

When in 1917 the value of transfusion as a routine measure in the treatment of hæmorrhage had become fully established in the casualty clearing station, it was felt that an attempt should be made to save some of the patients who died before arrival at these units. Although the difficulty of performing transfusion in aid posts and dressing stations was fully appreciated, the conditions in certain parts of the line did not preclude an attempt to save a few of the severely wounded who might otherwise die during the journey back from the line. In order to train a certain number of divisional medical officers in the technique of transfusion, a centre was formed in connection with a group of casualty clearing-stations in the Third Army area to which field ambulance and regimental medical officers could be sent for instruction. On completing their course of instruction, these officers were provided with the apparatus necessary for performing transfusion and returned to their units. By these means several divisions came to possess one or two medical officers specially skilled in the treatment of badly wounded men and capable of performing transfusions when circumstances permitted.

In addition to this educational work the officer in charge of

the centre made a point of being present on the occasion of any large trench raid taking place in the army area in order to perform transfusion in case of need. The locality chosen for performing transfusions depended on local conditions; in some cases it might be a well-equipped aid-post and in others the advanced dressing station. Whatever may have been the clinical value of this arrangement, the moral effect upon the men "going over" was so satisfactory that the combatant services soon got into the way of sending back word of an impending raid to the shock centre. In certain cases when several battalions were taking part in an operation, a special site was chosen to which badly wounded men could be conveniently sent from the various aid-posts for purposes of resuscitation and transfusion. Captain Norman Guiou, of the Second Canadian Division, and Major Holmes-à-Court, of the Australian Medical Corps, on several occasions made excellent arrangements of this description for dealing with the severely wounded, and a certain number who would undoubtedly have otherwise died were thereby saved.

When for different reasons transfusion with fresh blood was out of the question, use was made of corpuscles preserved according to the method already described. A store of preserved blood was kept at the centre from which supplies could be drawn for transfusion in the forward area. For convenience of transport the box in Fig. 7 was found to be useful. It was made sufficiently large to carry two bottles, each capable of holding a litre of blood. The compartment in the box was for holding a supply of ice. When preserved blood was employed transfusion could be performed in any dressing-station, however poor its equipment; the only apparatus required was a funnel and tube with instruments for cutting down on a vein if necessary. These were kept wrapped in sterilized lint in the hollow of the lid. Warm water could always be obtained locally for warming the blood to body temperature.

Although the value and practicability of blood transfusion in the divisional area were fully recognized towards the end of the war, its scope was restricted by various conditions. In the first place transfusion could only be undertaken during periods of ordinary warfare when the number of wounded passing through the dressing stations was somewhat limited. Secondly, transfusion in the divisional area was applicable to stationary rather than mobile warfare, for it was seldom that arrangements for transfusion could be undertaken when units

were continually on the move. When, however, a definite line had been established and well-equipped dressing stations were in use, transfusion became a practicable measure and could be easily undertaken during a period of quiet or moderate activity.

Indications for Blood Transfusion.

These may be considered under the following headings :—

(1) The pre-operative treatment of hæmorrhage and shock.
(2) Transfusion during operation.
(3) Transfusion after operation.
(4) Transfusion in cases of severe carbon monoxide poisoning.
(5) Transfusion in cases of septicæmia and chronic sepsis.

The Pre-operative Treatment of Hæmorrhage and Shock.— Reference has already been made to the employment of other restorative methods in the resuscitation ward, and it is of course in only a relatively small percentage of the cases admitted that transfusion is desirable. In severe hæmorrhage, " the proper substitute for blood is blood," and therefore a serious loss of blood furnishes the clearest indication for the employment of blood transfusion. In the case of a severe wound of a limb associated with serious blood loss, it is well to have a tourniquet in position or at hand, lest the bleeding recommence.

It must be borne in mind that in very desperate cases where the blood volume has been greatly reduced for some hours by hæmorrhage and the patient is very restless, pallid, and gasping for breath, transfusion performed at this stage is seldom successful, and the patient may die during the transfusion or very soon after. It may be worth while to give such cases the benefit of transfusion during periods of stationary warfare, but during periods of great activity the time of the transfusion officer will probably be unprofitably spent on such patients.

In cases of moderate hæmorrhage and shock, where the necessary apparatus is available, estimates of the hæmoglobin percentage and the blood volume, in addition to the determination of the blood pressure and the character of the pulse, will afford scientific data wherewith to ascertain the exact condition of the patient and to gauge the element of shock and loss of blood in each particular case. Thus a hæmoglobin reading below 75 to 85 per cent. and a blood volume of 60 to 70 per cent. indicate a moderate hæmorrhage and shock, whereas in a case of shock the hæmoglobin reading may be normal or even above normal.

In the more severe cases of this group experience has shown that it may be well to wait an hour or two before having recourse to blood transfusion. Rest, warmth and the ordinary resuscitation measures may by that time render many such cases quite fit for operation; if at the end of two hours there is no improvement, transfusion should be done. Less severe cases of this group usually improve sufficiently with the ordinary measures of réchauffement, and are soon in a condition to stand operation; if at the end of two or three hours the progress of these patients is arrested and they are not yet in an operable state, transfusion should be performed. Gum-acacia solution may be used in the milder cases of this group, but it is not so efficacious as blood transfusion in the severer types of wounded men. Kenneth Walker found that of the cases temporarily resuscitated by gum-infusion in the field ambulances, 70 per cent. required blood on reaching the casualty clearing station.

During periods of activity when there is a great rush of cases, the period of observation may require to be extended from two to three or four hours before transfusion is employed. The possibility of gas gangrene in patients with a prolonged very low blood pressure should be borne in mind as a possible explanation of their condition.

In actual practice, and particularly in "rush periods," it is probable that the more elaborate methods of estimating the degree of blood loss and shock will not be employed, and the surgeon will rely on the general aspect of the patient, his pulse, and possibly his blood pressure, in making a decision whether to transfuse or not. He will probably be wise if he transfuses in any doubtful case, and in the severe cases he will get better results from blood transfusion than from the injection of 6 per cent. gum solution; the results of the two methods of treatment afford a striking contrast in cases of hæmorrhage.

In wound shock it must be borne in mind that reduction of blood volume is also a striking feature; in shock without hæmorrhage this reduction is present, but not to such a degree as when hæmorrhage has taken place as well. The hæmoglobin reading in cases of pure shock is high; it may be normal or above normal. Hitchings, Eisenbrey and Lenhart found that in shock the blood concentration might be increased up to 20 per cent., but other considerations demonstrated that this concentration was not the primary cause of shock, whereas Mann and Cannon attribute great importance to the increased concentration and to the loss of plasma in shock. Crile, however, points out that if increased concentration were the cause

of the small amount of blood, and if circulatory failure was due to a " plasma hæmorrhage " into the tissues, then adequate transfusion should prevent and cure shock; nevertheless, transfusion has not proved to be a specific cure. Crile therefore concludes that the transference of plasma is probably merely an adaptive protection, and that the changes in the blood are secondary, and are not a primary cause of exhaustion.

Captain Oswald Robertson recommended that on account of the less satisfactory results from blood transfusion in cases of shock after hæmorrhage, other suitable fluids more easily procurable than blood—*e.g.*, the 5 per cent. gum-acacia solution of Bayliss,—should be tried in the first instance, and that blood should be kept in reserve if these fluids failed to effect sufficient restoration. He admits, however, that certain cases of shock are very definitely benefited by blood, but argued that a suitable fluid substance might have effected the same result. In the opinion of Walker and Gordon-Taylor the value of blood transfusion in shock far exceeds that of gum infusion. In their hands the cases of severe shock have responded far better to blood transfusion than to gum, and they consider that the former treatment should always be preferred in severe cases whenever it is available.

In cases of severe hæmorrhage large amounts of blood, *e.g.*, 900 to 1,000 c.c., are best given, and it is better in the cases of hæmorrhage requiring transfusion to err on the side of giving too large rather than too small a quantity. Cases of shock were usually given 500 c.c. to 600 c.c. of blood.

Transfusion at Operations.—Patients who have penetrating wounds of the abdomen and chest are perhaps best transfused immediately after operation. Surgeons have emphasised the importance of gas and oxygen in abdominal cases as an anæsthetic, and it is imperative to combine this with local anæsthesia induced with solutions of novocaine.

Dramatic as have been the results of blood transfusion in some cases of penetrating wounds of the abdomen, it is nevertheless unquestionable that transfusion is relatively less successful in wounds of that portion of the body than in the severe and complicated wounds of the extremities, associated with damage to large blood vessels, and in severe wounds of the thorax. Statistics are perhaps of little value in determining the worth of blood transfusion, but it is interesting to note that the mortality after blood transfusion in the case of single large wounds, chiefly fractured femur cases admitted into a casualty clearing station during the battle of Cambrai in 1917, amounted

to 28 per cent., whereas in the case of abdominal injuries the recovery rate was only 21 per cent. In both series of cases only the worst cases were transfused.

On the other hand, in a series of 55 cases of abdominal or abdomino-thoracic wounds transfused and operated upon by Gordon-Taylor—a series which included practically every case of such injury which reached a forward casualty clearing-station alive—20 cases recovered (36·3 per cent. recovery rate). Of these admissions, five, though transfused, failed to respond sufficiently to make operation possible, and, dying without operation, served to swell the mortality rate in this series.

Another series of 34 abdominal cases, with pulses over 120, similarly treated with blood transfusion showed 14 recoveries (41 per cent. recovery rate); and still another series of 32 cases, with pulses of 140 and upwards, transfused and operated on gave 12 recoveries (37·5 per cent. recovery rate).

The results in this series of desperate abdominal cases may be fortuitous, but it is interesting to compare them with some of the figures published before blood transfusion became such a relatively common practice. In June 1917, it was said: "The pulse is of the greatest importance. Of 145 cases with pulses over 120 only 16 recovered, a recovery rate of but 11 per cent."; and it was believed in the earlier stages of the war that operation should not be performed on a man with a pulse over 140. Blood transfusions have rescued many patients who were almost moribund from gun-shot wounds of the abdomen, and have more than trebled the recovery-rate of these desperate cases.

Post-operative Transfusion.—In many cases it is obvious that the transfusion should be done as soon as the operation is completed, but in some, especially if gas and oxygen have not been the anæsthetic employed, it may be well to adopt an expectant attitude for an hour or two after the operation, in order to ascertain whether the depression be due to the effect of the anæsthetic employed. If no improvement takes place then transfusion of blood should be adopted. It has been recommended that if blood has been employed previously, recourse should now be had to injections of gum, and that only if the gum fails to effect the necessary improvement should transfusion be practised for a second time. No harm has been seen in cases of repeated transfusion, and better results will be obtained with blood than with gum in these cases.

Transfusion in Severe Carbon Monoxide Poisoning.—Blood transfusion has been employed in this connection on several

occasions. Bruce Robertson quotes two cases in which some men, as a result of a shell explosion, were buried in a dug-out in which some combustible material caught fire. In spite of venesection and the withdrawal of 1,000 c.c. of blood, only moderate relief was obtained, the condition of the men remained very grave, and their colour was still of a bluish-grey hue ; the blood was almost black and of a peculiar syrupy consistence. Blood transfusion (1,000 c.c.) showed no immediate result, but on the following day a marked improvement was evident, and the cases progressed to recovery. Gordon-Taylor assisted in each transfusion, and his experience led him to practise transfusion in two precisely similar cases at the beginning of 1918 ; exactly the same phenomena were observed, and the cases again recovered.

Transfusion in Septicæmia and Chronic Wound Infection.— During the war a limited trial was made of the treatment of severe pyogenic infection by whole blood transfusion from immunised blood donors. The rationale for this use of blood transfusion is a possible anti-bacterial mass action, obtained by the employment of a large volume of immune serum, (*e.g.*, 900 c.c. as against the 20 to 40 c.c. of anti-streptococcal serum usually injected) ; " a protein shock therapy " on a considerable scale and the employment of a homologous serum ; the possible sensitising of the patient towards a vaccine by means of the immune serum, the same vaccine being employed for the patient as was used to produce immunity in the blood donor, and the replacement of red blood cells in the circulation of the patient instead of those broken down by the hæmolytic activity of the streptococci, thus combating the anæmia produced by the infection.

In the experience of one officer, Captain H. C. B. Fry, cases of chronic suppurative infection of wounds, in which this vaccination transfusion was employed, made a rapid and satisfactory recovery. The cases in question were in a stationary and chronic condition, and after this treatment the wound surfaces rapidly assumed a more healthy appearance and the amount of discharge diminished.

In the cases of acute septicæmia the result was almost uniformly bad, but in all the method was only adopted as a last resort, too late for any hope of success.

Polyvalent vaccine from various strains of streptococci was employed. Each donor had six to nine injections, given at intervals of about five days. The amount of the final dose was on an average 120 to 150 million streptococci and 400

million staphylococci, where a mixed vaccine was employed. The period of immunisation lasted a month, and the interval between the last dose of vaccine and the giving of blood was on an average about 5 days (1 to 31 days). The amount of blood transfused was generally 900 c.c., but varied from 450 c.c. upwards. Fry thought that the method might prove of value in the treatment of malignant endocarditis, acute and chronic suppurative diseases of bones or joints, and in puerperal septicæmia.

If a patient has a fairly good volume with a high bacterial blood count, it may be wise to venesect just before transfusion.

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CHAPTER VI.

GAS GANGRENE.

THIS disease, known by the name of Acute Spreading Traumatic Emphysematous Gangrene, was comparatively rare before the war. In no previous campaign had the disease figured to any great extent, but under the name of Gas Gangrene it quickly assumed a position of tragic importance, more especially on the Western Front. In the early period of the war, as is now known, everything was in its favour. In the retreat from Mons there was no possibility of early surgery. The ambulance trains were defective, evacuation difficult and the journey to the base long.

Even when the line became stabilized there was comparatively little early treatment of the majority of wounds until the spring of 1915. The first improvement resulted from an observation made at the base, namely, that the disease was much less common in those wounds that had been drained at the front. The pathology was, however, but little understood, and treatment, both at the base and at the front, was for a considerable time confined to drainage, incision and amputation.

When operative interference became the established practice at casualty clearing stations the surgeon was still handicapped. In battle periods, when the large number of wounded compelled rapid evacuation to the casualty clearing stations, the numbers themselves prevented adequate surgical treatment. In quiet times the method of evacuation by convoy from field ambulance to the casualty clearing stations, which in some instances was not continuous, caused many of the cases to arrive late. When, however, the operative treatment at casualty clearing stations was commenced, there was a continued fall in the incidence of the disease, and a further improvement followed when a systematic excision of muscle, which started in the autumn of 1915, became an established practice. Whenever circumstances compelled a return to early war conditions, and treatment was perforce transferred to the base, the number of cases of the disease again increased. The experience of No. 7 General Hospital, St. Omer, may be quoted in this connection. This hospital received all the more

severely wounded that passed through the clearing stations in the Merville and Béthune areas. It was first used for this purpose in June 1916, and during the many months in which it continued in active work gas gangrene was practically unknown. This does not mean, of course, that cases of gas gangrene were not seen in the clearing stations, but only that those cases which were quickly and adequately treated, and in which the fulminating form of the disease did not develop, were cured of or saved from the disease.

The conditions which determined the incidence of the disease have always remained more or less a mystery. It was more frequent in certain sectors than in others, but even in individual sectors the amount of the disease varied on different occasions, although the circumstances in other respects were practically similar. It was worse in cold weather, especially when the ground was wet. This possibly was connected with the more frequent occurrence of wound shock. The wounded arriving at the end of an attack were always more likely to be affected than those collected early. On the other hand, it was a remarkable fact that many soldiers who had lain out in shell holes for days with bad wounds were found free from the disease when collected. This, however, was most probably a case of the survival of the fittest. An increase in gas gangrene was noted in attacks in wooded country or where the fighting swayed backwards and forwards, for here again the collection was extremely difficult. In the final advance over the devastated Somme battlefield the disease is said to have diminished, and this has been attributed to the fact that the battlefield had been unmanured and exposed to the sun and air for many months. At the same time it must be remembered that in this fighting the collection of the wounded was rapid, the number of shell injuries comparatively few, the weather favourable and the operative facilities at the clearing stations good. In the northern portion of the advance, south of Arras, the percentage of gas gangrene cases was not materially different from that obtaining in some of the fighting in June, which took place north of Béthune, and in an area where the soil had recently been tilled.

It is extremely difficult to give any reliable figures as to the frequency of the disease. Most probably the only figures which are reliable are those taken in the summer of 1918, when the serum treatment was being tried. In 1915 some statistics were collected in the Béthune area. These figures showed a percentage of about 5 in No. 1 Casualty Clearing Station. Other figures, collected from French and German sources, put

the percentage between 2 and 13, the latter figure being from a French source. The figures already referred to as being taken in the summer of 1918 can be trusted, for they were carefully observed, and were of sufficient magnitude to eliminate error. They referred to parts of the line north of Béthune, and show a percentage of rather over 1 amongst the wounded arriving at a clearing station.*

Ætiology.

Soil containing the causative bacilli is directly implanted in the wounds, or carried in by fragments of shells that burst after burying themselves in the ground. The clothes of the soldier—and to a less extent his skin—were always more or less contaminated with dust and mud. Bullets, and especially shell fragments, that had touched no object since leaving the muzzle could, therefore, easily implant the organisms. Pieces of clothing carried in by shell fragments were responsible for a very large number of the cases, the lacerated tissues produced by the shell fragments offering a favourable pabulum for the bacilli contained in the clothing.

Before the war and in the early part of the war the disease was looked upon as a general infection of the limb, the terms " gaseous cellulitis " and " massive gangrene" reflecting the ordinary views. While the bacilli were found present in nearly all wounds, it was recognized that they did not necessarily gain a footing in the body, or produce more than local signs. In certain places, namely the muscles, the cellular tissue, pleural blood, hæmatomata and brain, it appeared they could live and flourish in varying degrees; while the peritoneum and the cavity of joints, though the latter might contain gas, were practically immune. Comparatively early, Sacquépée, the French pathologist, and Kenneth Taylor, an American pathologist working with the French, advanced the view that the disease was in the main an affection of the muscles. This view was later supported by Dunn, Frankau, McNee and Wallace of the British service, who pointed out that the disease hardly ever occurred, or was but little to be feared, except in the case of wounded muscles and of tissues infiltrated with blood. It certainly appeared that the disease could in most cases be cut short by the excision of the muscles, though this treatment failed, and failed to the end, to arrest the so-called

* See p. 148.

fulminating cases. The muscle infection view of the disease has not been accepted by all, and doubt has recently been thrown upon it again by the laboratory workers in England, who maintain that the disease can be produced in animals as easily by injection of cultures into the subcutaneous tissue as into the muscles.

Clinical observation has clearly shown that a defective blood supply is the principal cause of the organisms gaining a footing in the body when they have once been introduced into wounds. A defective blood supply may be brought about in many ways. Death of the tissue may be produced by the blow of the projectile or by the occlusion of vessels, brought about either by actual severance or thrombosis following contusion. Among other causes may be included inefficient splinting which leads to injury of vessels or tissue, constriction of the limb by tourniquets, bandages, or badly applied splints, damming back of discharges by packing introduced into the wound or by dressings in which the discharges have been allowed to dry and cake.

Hæmorrhage, cold and shock, by producing a low blood pressure, were also potent factors. In the latter part of the war it came to be recognised more and more distinctly that a low blood pressure was extremely dangerous, and that the period of resuscitation must be shortened as much as possible. Some stress has also been laid on both a local and general acidosis as favouring the growth of the organisms. This acidosis was considered to be connected with excessive exertion, fatigue, cold and a deficient blood pressure.

It is very certain that the cutting off of the blood supply to a muscle was a very important factor in its infection. Some work done by Campbell and Pennefather is interesting in this connection. These observers studied the blood supply of muscles by means of radiograms taken after injection of bismuth into their arterial supply. Some muscles, such as the gracilis, are dependent on a single main artery for their nourishment; others, especially the segmental muscles, have two or more arterial supplies. Further observation showed that the circulation within a muscle is largely a terminal one, and that, while the capillaries anastomose, the larger trunks do not. The severance or thrombosis of the artery in the case of a muscle with a single supply will render that muscle bloodless. In the case of a muscle with several blood supplies the severance or thrombosis of an artery, while it will not kill the entire muscle, will lead to the death of its own particular distribution.

These observations seem to offer an easy explanation of some well-known clinical facts.

(1) That a dead or gangrenous muscle may be found in the midst of a healthy group.

(2) The arrest of the disease at one point in a muscle.

(3) The subsequent death and infection of a muscle that was healthy at the time of the primary cleaning operation. Here it would appear that the surgeon, in performing the cleaning operation, had inadvertently interfered with the blood supply

Morbid Anatomy.

This can best be studied under two heads :—

(A) Group gangrene, and

(B) Segmental gangrene (massive).

These varieties are not really entities, but the division is convenient from a descriptive point of view.

Group gangrene, where the gangrene is limited to a single muscle group, can be further subdivided into :—

(i) A wounded muscle or muscle group from which the blood supply has been cut off.

(ii) Infection of a wounded muscle or muscles with an intact blood supply.

In the sub-group (i), if the limb be dissected, it will be seen that a certain muscle or muscle group is dead, but in other respects very little altered except where wounded. Next to the dead muscle lie perfectly normal contractile muscles. The disease, so to speak, is a longitudinal one; infection finds difficulty in passing from one muscle to another, but easily extends up and down a muscle from end to end. Next, the muscle involved changes colour. The colour varies in different cases, depending upon the bacteria present or on the predominance of one bacteria in a mixed infection. The first alteration is the appearance of a salmon-red colour. This has been called the stage of " red death." (Plate I.) About this time the gas generated in the muscle becomes obvious to the eye as bubbles which can be pressed up and down between the fibres. The substance of the muscles becomes friable; the colour then changes to yellow, and possibly in the end the muscle becomes black and diffluent. The connective tissue lying in immediate contact with the diseased muscles may be little altered. At other times it is filled with white, yellow or blood-

(*a*) A dead piece of gluteus maximus muscle, showing spaces once occupied by bubbles of gas.

(*b*) Piece of tibialis anticus, showing olive green colour of late stage of gangrene.

Thigh from a case of gas gangrene.

Amputated arm, showing commencing gas gangrene in supinator longus muscle.

stained œdema. Gas may or may not be present in the areolar tissue, and when it is present tends to find its way along the main vessels of the limb. It also escapes into the subcutaneous tissues, following the perforating arteries, and often extends far beyond the limits of the disease.

Plate II represents a dissection of the thigh of a man who died from multiple injuries and gas gangrene of the thigh. A wound is present over the vastus externus, part of which has been carried away. The resulting dirty cavity can be seen, as can also the infected subcutaneous tissue, which is of a dirty yellowish-green hue. The vastus externus, although wounded, did not become gangrenous. The missile passed behind the rectus tendon and lodged in the vastus internus; the latter muscle was gangrenous throughout. The change of colour of the muscle can easily be seen. There were bubbles of gas between the fasciculi; the edge of the sartorius was similarly affected. The other muscles were normal. The inter-muscular connective tissue showed but little alteration. Death occurred 56 hours after receipt of the wound.

Plate III exhibits the changes in the subcutaneous tissues in a striking degree. In this case there was a compound fracture of the humerus just above the elbow joint, and, in addition, a penetrating wound of the chest. As the patient's condition was so precarious and there was no radial pulse, the limb was amputated. The supinator longus is seen in the diffluent stage of gas gangrene, yellowish-green in colour, devoid of tone and form, and could be dented and moulded with the finger. The remaining muscles of the forearm were normal and contractile.

In the sub-group (ii), infection of wounded muscle or muscles with an intact blood supply is a comparatively rare phenomenon, living muscles showing a very great resistance to invasion. Were this not so, the disease would be even more to be feared than it is. Ordinarily, wounds are only contaminated with the bacilli which live in the muscle killed by the projectile. When actual infection takes place, the spread of the disease can be seen as follows. The surface of the actual wound is dry or dirty-looking, or in some cases black. Next to this is a red area which is limited towards the sound tissue by a yellow, sinuous line. This line is raised and hard to the touch; next to it lies the normal contractile red muscle. The microscopic appearance will be described later on.

In segmental or massive gangrene all or nearly all the muscles of a segment of a limb distal to a complete arterial

lesion, deprived of their blood supply, die and become infected. The appearances are similar to those seen in the first sub-group of group gangrene, noted above, except that the muscles may not be wounded. The colour of the muscle will depend on the length to which infection has passed, and the amount of gas and œdema will vary in like manner.

Four organisms are mainly responsible for the disease. In injection experiments these organisms produce somewhat different appearances. Unfortunately in man, owing to the difficulty of identifying the bacilli, there is difficulty in determining the appearances peculiar to each variety of infection. But from a study of the disease in man, and experiments on animals, the following would appear to be the naked-eye changes produced by the infecting agents :—

(1) *Bacillus welchii.*
   (*a*) Yellow œdema, sometimes blood-stained
   (*b*) Large gas production of short duration.
   (*c*) A salmon-red colour of the muscles.
   (*d*) Soft pulpy muscles.
   (*e*) Slight sourish smell.
   (*f*) Bronzing of the skin.
   (*g*) Appearance of fat globules in the discharge.

(2) *Vibrion septique.*
   (*a*) Blood-stained œdema.
   (*b*) Large gas production.
   (*c*) Deep red colour of the affected muscles.
   (*d*) An odour which is not putrid but rather rancid in character.

(3) *Bacillus œdematiens.*
   (*a*) Colourless gelatinous œdema.
   (*b*) A small amount of gas production.
   (*c*) Pale pink colour of muscles. Deep red in a heavily infected area.

(4) *Bacillus sporogenes.*

This bacillus may obscure the features of any of the gangrene types, but is most often associated with *B. welchii*, owing to the fact that the more rapid *Vibrion septique* and the more toxic *Bacillus œdematiens* generally outrun the *Bacillus sporogenes* in heavily mixed infection. The putrid type of gangrene which gets this character from the presence of *Bacillus sporogenes* is generally, apparently, a 24–48 hour case or longer, not one of the 8–24 hour

galloping ones. *Bacillus sporogenes* does not seem able to start off quite so quickly as *B. welchii*, *Vibrion septique* or *B. œdematiens*. There are two distinctive features :—

(*a*) Olive green colour of the muscles, the colour turning to black.

(*b*) A putrid odour.

Since nearly all wounds are contaminated, the questions may be asked, why the disease progresses in some cases and not in others ; why it returns after amputation, and why in certain cases treatment fails to arrest it. There is no proper answer to all these questions. These differences may depend upon the different infecting agencies, but no precise information is available on the subject.

The advance in most cases is a local one, spreading centrifugally. Metastases may occur in certain places, such as the site of hypodermic or saline injections ; in the buttocks, which are subject to pressure ; and in a few cases, shortly before death, in an unwounded limb. Bacilli are often found in the blood stream, but this condition may be transitory and is not necessarily of serious import. *Vibrion septique* causes a septicæmia more often than any other.*

Everything seems to point to the fact that a death of the tissue is a necessary antecedent to the spread of the bacteria. Consequently, there is no difficulty in understanding the spread of the infection in a muscle already deprived of its blood supply. The question is what kills the tissues when the blood supply is intact.

Recent experiments have shown that the presence of calcium salts, owing to their depressing effect on the tissue, is an important factor in enabling the bacilli to gain a footing. Calcium was present in the soil with which the wounds were contaminated.

Taylor advanced the view that the gas produces the death of the tissues by its disruptive effects, but probably it only plays a secondary part by producing a tension in the limb which interferes with the blood supply.

D'Este Emery has shown how the toxin repels the leucocytes ; indeed the absence of any reaction is one of the most striking phenomena of the advance of the gangrene. This observation, however, seems to explain better the failure of nature

* A detailed microscopic description of the spread of the gangrene will be found in the volume on Pathology.

to arrest the disease than to offer an explanation of how the living tissues are killed, so as to afford a pabulum for the bacteria.

None of the above facts seem to offer an adequate explanation of the destruction of the living tissue. The key to the problem lies in the observation that bacteria washed free of toxin are comparatively harmless. On the other hand, the toxins elaborated by the organisms in the case of the three pathogenic anaërobes most concerned with the production of gas gangrene, namely *Bacillus welchii*, *Vibrion septique* and *Bacillus œdematiens*, cause considerable alteration in healthy living tissue. This is clearly illustrated by the local lesions of œdema and necrosis which follow upon the intramuscular injection into animals of sublethal doses of the filtered sterile toxin of these organisms.

If the bacteria find a suitable nidus in tissue killed by an injury or in tissue whose vitality has been lowered by a calcium salt introduced by the projectile, they elaborate a toxin which kills the tissues either by direct action, or possibly, as put forward by Bashford, by producing a thrombosis in the vessels by its action on the endothelial lining. This suggestion is borne out by the work of McNee and Dunn on the microscopy of the advancing edge.

The phenomenon of gas production, which gave the name by which the disease was known in France, is an important one from a clinical point of view, though the part it plays in the spread of the disease is but a secondary one. It is generated about the time that the muscle begins to change colour. It produces swelling and tympanites of the limb before it gives rise to a crepitation which is discernible by the fingers, though even then, as pointed out by Maybury, a stethoscope if used with a varying pressure may reveal a crackling. At this stage the muscle floats if thrown into water. A little later the gas becomes obvious to the naked eye as little bubbles lying between the fibres, and these bubbles can be displaced up and down the muscle by pressure. (Plate IV.) If the fascia of the limb is intact, or nearly so, the gas quickly increases the swelling and tension of the limb, and this tension is liable to render the skin white. If the gas can find no exit from the wound, it is forced into the areolar tissue between the muscles. It follows the line of least resistance, and finds its way along the great vessel through the fascia, and by means of the perforating arteries reaches the subcutaneous tissue, through which it rapidly spreads far beyond the limits of the

Cross section of thigh from a case of gas gangrene.

disease. When it reaches the skin, the phenomenon of crepitation becomes especially marked. In some cases incision of the skin is followed by the escape of gas, which burns on the application of a match.

The presence of gas can be demonstrated by X-ray photographs, and this means of diagnosis was used in sub-acute cases at the base hospitals. Owing to the fact that gas production in quantities that will show in an X-ray plate is a comparatively late phenomenon, this means of diagnosis cannot be relied upon in the acute cases.

Symptoms.

When the wound is an open one, it may simply present bruised and torn muscle. Very often, however, the appearance is peculiar, and the exposed muscle shows a dry deep purple or blackened surface, which at first sight suggests dried fæcal matter. Later on the wound becomes moister, and there is a thin, foul discharge, mixed with bubbles of gas and droplets of fat. Still later the discharge becomes copious and bright yellow, the yellow colour being produced by hæmolysis. The amount of odour present varies greatly, but at times it becomes penetrating and over-powering. In such a wound infection may be purely local, and the symptoms of absorption absent. When the disease really gains an entrance into the body, it may be divided for purposes of clinical description into three groups :—(*a*) Group gangrene, (*b*) Segmental or massive gangrene, and (*c*) Fulminating gangrene. The first two groups correspond to the types of infection described under the gross morbid anatomy, and the third group is a purely clinical type which may originate in either of these.

No case is immune in which muscle has been touched, even if the projectile be a bullet that has not become deformed. The onset may be extremely acute, and constitutional symptoms and well-marked gas production present themselves within four hours. A patient left in good condition may be found moribund in a few hours. Many patients about whom there was no anxiety at night have been found in the morning in a dangerous condition, the infection gaining ground while the patient was asleep or without causing him to summon the nurse. The early symptoms are pain in the affected parts, a feeling of malaise and restlessness, a rise in temperature and pulse rate. Vomiting may be an early symptom, and later on may become one of the most distressing phenomena of the disease.

Drummond and Taylor have pointed out that a rise in the blood pressure may usher in the disease. This clinical observation is interesting, in view of the fact that *Vibrion septique* sterile toxin, run into the venous system of a rabbit whose blood pressure is being registered on a kymograph, shows a quite marked and definite rise in blood pressure. The picture finally ends in a steep fall and death, owing to the direct action of the toxin on the heart muscle.

Group Type.—The limb at first may show no departure from the normal, or it may be swollen to a greater or less extent. The skin at first is normal, then becomes blanched and tense. The veins, as a rule, do not show up. The area round the wound, or even the whole limb, becomes tympanitic. In wounds which have been operated upon and which do not appear to be doing well, it is of importance to distinguish the resonance which has been produced by the entry of air into the wound from the resonance caused by the gas production. As the swelling increases, the skin becomes dirty white and the veins may become prominent. Mottling of the skin is noted, and purple patches appear which are caused by the cutting off of the blood supply owing to the death of the under-lying muscles. Finally the skin takes on a greenish hue.

It is important to remember that gangrenous muscles may be covered by perfectly normal skin. In certain cases a peculiar bronzing of the skin may be noted. It may occur near the wound, or in some cases at a considerable distance. Its significance and cause have not been fully explained, but it is probably associated with the *Bacillus welchii* infection. Its appearance may mean little or may be the beginning of extensive sloughing of the skin and death of the patient. Incision into such an area may reveal little or nothing, or disintegration of the subcutaneous tissue.

Massive Type.—A limb already gangrenous suddenly becomes tympanitic, and the patient shows the early common symptoms, such as pain, vomiting, and a rise of temperature, or the gangrene tympanites and clinical signs manifest themselves at one and the same time. In both varieties the appearance of the skin is that seen in arterial gangrene, but bacterial infection produces a rapid appearance of the signs of decomposition.

Fulminating Type.—This clinical type is exceedingly dangerous. Surgical measures, such as are sufficient to save life and limb in the first two, are often unavailing. At first it cannot be distinguished from the group or " massive " type, and it is only the failure of surgical treatment to arrest the

disease which reveals its nature. It is often seen in a thigh amputation for gas gangrene of the leg. Here amputation through apparently normal tissue is followed, after perhaps a few hours of apparent amelioration, by recrudescence of the disease, which extends rapidly to the trunk and quickly proves fatal. It is in this type that the gangrenous process in the skin can be followed from hour to hour.

Late common Symptoms.—If the disease is not sufficiently acute to cause death in a short time, the skin of the whole body first becomes dirty looking and then yellow, the yellow colour being very noticeable in the whites of the eyes. This universal discoloration of the skin was perhaps more obvious in the early part of the war when the surgical treatment was not properly understood. If cases do not progress favourably all the symptoms undergo an aggravation. The pulse becomes more rapid, then running; vomiting is frequent and exceedingly distressing; the extremities become cold and blue, the body covered with sweat, and the temperature, which has been raised, falls. This fall in temperature was sometimes, in the early part of the war, regarded as a favourable sign, though it really ushered in the end. The mind remains, as a rule, extraordinarily acute even to the end.

Treatment.

There are two important points to be noted.

(1) The avoidance of all things that tend to restrict the blood supply, whether those be constriction by tourniquet, tight bandaging, continued damage caused by inefficient splints, the damming back of discharges by dressings, or the persistence of a state of shock.

(2) Mechanical cleaning of the wound at the earliest possible moment. The importance of early surgical interference became more and more obvious as the war went on. In the end it came to be recognised that not only was it necessary to get the wounded man quickly to the clearing station, but that the cutting short of the resuscitation period of those too bad at first for operation was imperative. In the shortening of this period the infusion of gum saline or blood played a progressively greater part.

The actual treatment is governed by the state of the patient and the extent of the gangrene. Thus a patient who is in good condition can be submitted to an operation for eradication of the diseased muscles, while in another patient the same amount of disease may demand amputation.

Group Type.—When the patient is in good condition the mechanical cleaning of the wound is proceeded with in the usual way, adequate longitudinal incisions being used. Great gentleness is necessary, and care must be taken to respect even small blood vessels, otherwise another portion of the muscle may be deprived of its blood supply, and be found later dead and infected. Attention is focussed on the condition of the muscles. All muscles that do not contract or bleed, or are altered in colour, are removed. Certain muscles may require to be followed to their attachments. By this means a limb, which would have been sacrificed if crepitation and tympanites had been taken as the criterion of the extent of the disease, may be saved at the expense of a muscle or muscle group.

When the patient is in bad condition, as is most likely to occur in fractures of the long bones, the limb will probably have to be amputated through the fracture. If it is thought that a higher amputation is indicated by a tympanitic condition of the skin, it is well to investigate the condition of the muscles by skin incisions, starting at the level of the injury, and ascertaining if the muscles are dead at the level of the proposed amputation. Under war conditions it is seldom justifiable to amputate through the thigh for gas gangrene of the leg. In many cases it must be recognised that the amputation is a provisional one, and care must be taken to make it possible, later on, to fashion serviceable stumps rather than to attempt to make a permanent stump in the first instance. A guillotine amputation through the head of the tibia or through the knee joint, preferably the former, with removal of the heads of the gastrocnemii is usually sufficient.

Massive Type—This type is usually met with after injury to a main artery. Suture of the artery or, if this is not possible, the use of Tuffier's tubes as a prophylactic measure is to be recommended. When the gangrene is established, and the limb obviously dead, it is only a question of where to amputate. Here again the state of the muscles is the guide, and the limb should be removed at the lowest level of the living muscle. In some cases, where there is a gross injury such as a shattered joint or a fracture of the long bone, it may be necessary to disregard the extent of the gangrene and to amputate at a higher level than the injury.

Amputation through the knee joint or head of the tibia is to be preferred to amputation through the thigh.

Except in cases of grave danger, short flaps of some description should be furnished. Below the knee, where

the amputation will almost always be of a provisional nature, the guillotine method is often the best. In all amputations under war conditions, it is probably better to leave the flaps open or to suture them lightly over gauze. A non-closure of the flaps has also the advantage that for the next day or two the surface of the stump can be inspected, and this will render more easy the excision of muscles which are sometimes found dead within a few hours of amputation.

Fulminating Type.—This type is seen generally after amputation through the thigh. Its treatment is practically hopeless. It need only be said that re-amputation in these cases at or near the hip is almost uniformly fatal and should rarely be undertaken.

Serum Treatment.—Sera were used on a small scale by both the French and the Germans, comparatively early in the war, but it was not till 1918 that this treatment was used by the British. At this period a fairly extensive trial took place in the French and British armies. Even when different sera were available in suitable amounts the difficulties of arriving at a balanced judgment of their efficiency were very great. This was owing to the following causes :—

(1) The almost universal mixed infection of wounds.

(2) The want of an accurate knowledge as to the varieties of anaërobic organisms causing the disease.

(3) The want of a means by which an early diagnosis of the actual organism causing the infection in any particular case could be made.

(4) The lack of standardization of the sera.

The sera used in the British Army were those prepared against *Bacillus welchii* and *Vibrion septique*. They were anti-toxic sera. They were used therapeutically and in a certain sense prophylactically.

Early in 1918, Major Carrol Bull, of the United States Army, was attached to the British Army in order that he might make a trial of his anti-toxic *Bacillus welchii* serum. This was administered in the clearing stations to cases that had already developed the disease ; its use was, therefore, therapeutic. It was given as a rule intravenously, supplemented by subcutaneous and intramuscular injection, in doses up to 80 c.c. and repeated in some cases. Occasionally observers were struck with the improvement produced, but it cannot be said that the results were at all uniform.

Later on other sera prepared in England against *Bacillus welchii* and *Vibrion septique* were used with very much the same effects.

In June 1918, a trial on a larger scale was made of a combined anti-tetanic and anti-Welchii serum. This serum was used in what may be described as a prophylactic method. The trial was made in the part of the line that ran north from Béthune. Certain divisions were supplied with the combined sera, while those adjoining were given the anti-tetanic serum only. These sera were administered in the advanced dressing stations. A return was made of all cases developing gas gangrene before evacuating from the clearing stations.

Table showing details of above Experiment—May to September, 1918.

Anti-tetanic + welchii					Anti-tetanic serum only (control).				
No. of Wounded.	Cases of Gas Gangrene.	No. of Deaths.	Morbidity rate per 1000.	Case Mortality per cent.	No. of Wounded	Cases of Gas Gangrene.	No. of Deaths.	Morbidity rate per 1000.	Case Mortality per cent.
9,294	114	26	12·26	22·8	13,024	152	37	11·67	24·34

The area from which the men were collected was farm land which had been recently cultivated and on to which the troops had been driven back. The collection of the wounded was on the whole rapid. It is probable that this series comprises the only reliable figures in the whole campaign. It shows that gas gangrene occurred to the extent of little over 1 per cent. of all wounds, and may be compared for what it is worth with the 5–6 per cent. that was obtained in a clearing station in 1915, in the same area.

The mortality of the disease was about 22 per cent.

It will be seen that no appreciable difference in the incidence of the disease was produced by the two types of serum.

The comparison of the two sera was continued at the base, and here it appeared that the mortality of those cases that had been inoculated with the Welchii serum and developed gas gangrene was considerably less than the mortality of the other group, but several factors rendered the figures untrustworthy.

The failure of the serum to produce any effect at the front may have been due to the fact that the dose of Welchii serum

contained only one-fifth of the numbers of units it should have contained considering the body weight of a man and using the Bull unit of protection.

During the time covered by the above experiment and up to the end of the war, various brands of *Bacillus welchii* and *Vibrion septique* sera, either as single or double sera, were used in the clearing stations. Their use was mostly therapeutic.

The lack of a sufficient supply of any particular serum, the conflicting opinions of those who used them, and the conditions obtaining in the later stages of the war, which rendered the collection of observations difficult, have made it impossible to form a final judgment.

The French medical service in the latter part of the war used an anti-Welchii, anti-*Vibrion septique* and an anti-*œdematiens* serum. The method of employment was as follows :—

The cases treated were those in which gas gangrene was considered as likely to occur, such as cases of fracture of long bones, damage to main arteries and extensive muscular wounds. In the first place the three sera were injected either subcutaneously or intramuscularly about the damaged muscle. If after investigation it was considered that one or other of the three organisms was predominant, the appropriate anti-serum was pushed. Used in the above manner the sera produced a very favourable effect on the minds of the French surgeons, and the reports were somewhat enthusiastic.

It should be noted, in considering the value of serum therapy as applied to gas gangrene in the war that the production of all these sera was in its infancy. Final high titre products had not been obtained for adequate trial by the time of the armistice.

A small quantity of potent serum was at the disposal of the French service, owing to the work of Dr. Weinberg.

Encouraging results were obtained by Duval, Chutro and Delbet, and suggest that all efforts to develop such sera should be continued.

It may also be noted that German surgeons claim that much benefit resulted in their armies from the use of a polyvalent serum.

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CHAPTER VII.

TETANUS.

IN former wars tetanus was a calamity to be recorded and deplored; the war of 1914–18 has shown that it is one which can largely be prevented. The cause of the disease was only discovered in 1885, and the preparation of an effective anti-serum dates from 1892. The war of 1914–18 has been the first in which there has been any great opportunity for applying modern knowledge of the subject. Not only was that knowledge applied, but advantage was taken of the abundant opportunities for further study, and the large body of skilled clinicians and pathologists at the command of the military authorities enabled still further advances to be made. The pathology of tetanus and the many new facts which have been brought to light are fully discussed in the volume on the pathology of the war, where also full statistics are given. But the chief statistical data and a short summary of the pathology of the disease may be noted here.

With regard to the measures adopted for the study of tetanus during the war, in France all cases were notified to the A.D.M.S. (Sanitation) at General Headquarters. Further, the case sheets were, for the most part, submitted to analysis by the adviser on pathology and his colleagues. Analyses were published for the information of those responsible for treatment, one, by Sir W. B. Leishman and Major Smallman, in January 1917, and a second by Colonel S. L. Cummins and Major Graeme Gibson in March 1919. These analyses, together with certain papers read at conferences of the allies, contain the most complete information hitherto published as to tetanus in the British Expeditionary Force. In England more complete investigations were possible. In October 1914, the Director-General A.M.S. requested Sir David Bruce to devote himself to the study of tetanus in home hospitals. All cases were notified to Sir David Bruce, who published periodical analyses of them in the medical journals, followed in 1920 by a general review of the 1,458 cases he had collected. These papers, and especially the final review, contain authoritative statistical data of tetanus amongst wounded soldiers in England.

It early became apparent that tetanus presented many difficult problems, and in March 1916, a War Office committee

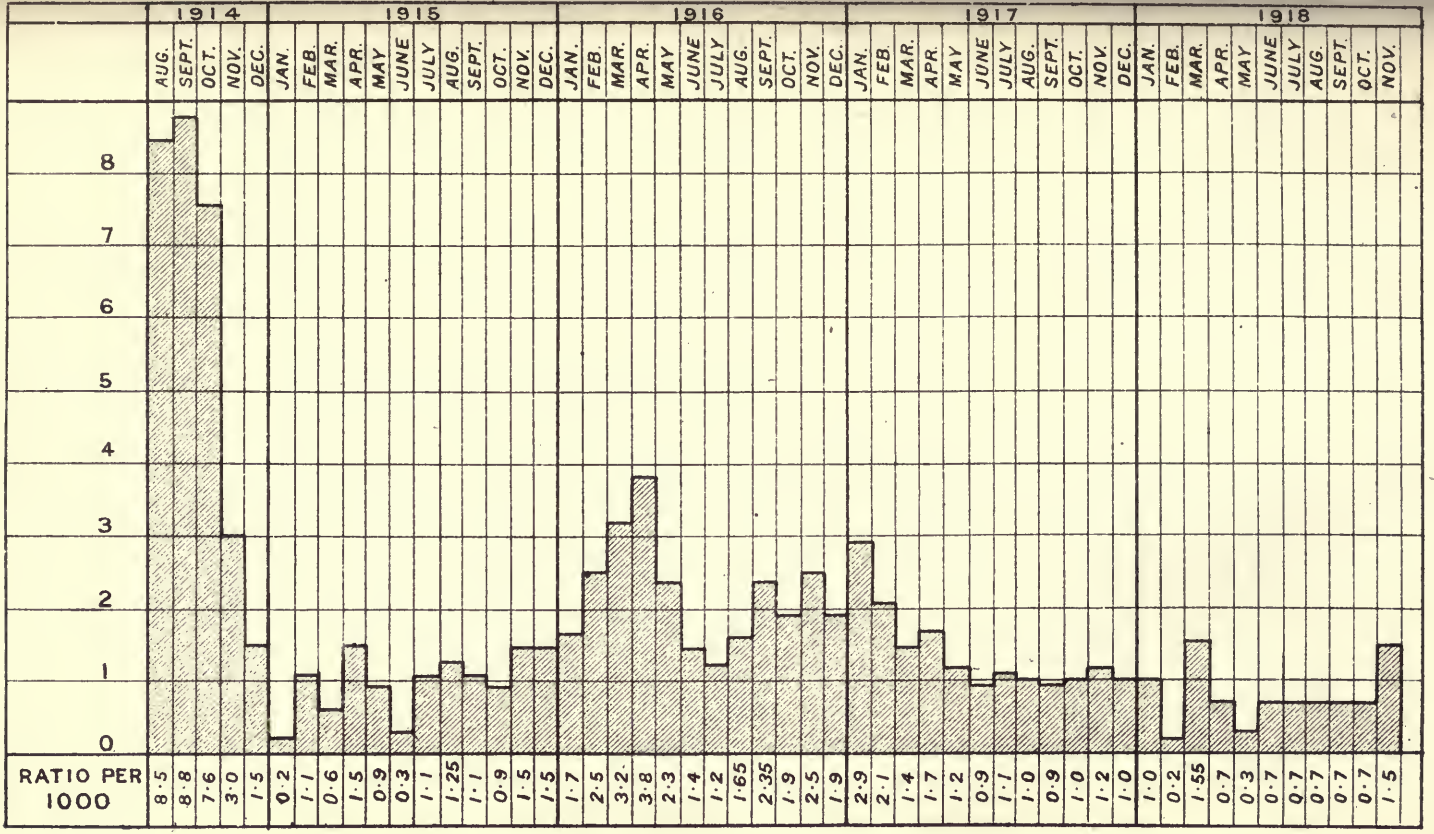
for the study of tetanus was formed with Sir David Bruce as chairman.* The committee met fortnightly during the remainder of the war and discussed all matters relating to tetanus. They were instrumental in initiating research on lines along which fresh information was needed and in urging improvements in preventive and curative treatment. They published a memorandum, which was revised from time to time, dealing with the diagnosis and treatment of tetanus, and which was issued by the War Office to all medical officers.

In September 1916, an important step was taken by the appointment of local inspectors of tetanus. In order to secure early skilled treatment for a disease, with which most medical officers were unfamiliar, some forty officers possessing the necessary experience were nominated by the War Office to different districts. Every case of suspected tetanus was required to be reported at once to the local inspector, whose duty it was to visit the case immediately, to offer any advice and help needed, and to fill up an independent and detailed report for the use of Sir David Bruce. This system of expert consultation proved of great value. While good use was thus made of the unrivalled opportunities for the study of tetanus offered by the war, it must be admitted that the records were not perfect. The incidence of tetanus during the first stages of the fighting can never be accurately known; during the retreat from Mons many of the severe casualties were, of necessity, left to fall into the hands of the enemy. Until attention was aroused by the frequency with which cases of the disease began to occur, they were not systematically reported even in England. At all times, when reports came to be analysed, many were found to have been filled up imperfectly. The statements and figures which follow must, therefore, be taken only as fairly close approximations to the truth.

Distribution.

The total number of cases of tetanus developing in British hospitals in France and Belgium is recorded as 1,071. In home hospitals 1,458 cases were reported, and practically all these were wounded in France and Belgium. The total

* The earlier members of this committee were Professor A. D. Waller, F.R.S., the late Professor H. G. Plimmer, F.R.S., Dr. A. T. MacConkey, Captain F. Golla (Secy.) and Professor F. W. Andrewes, F.R.S.; later were added Professor C. S. Sherrington, P.R.S., Dr. F. Ransom, Dr. R. A. O'Brien, Sir K. Goadby, Dr. W. J. Tulloch, Sir Frederick Mott, F.R.S., Dr. W. Harris and Major A. B. Smallman.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MONTHLY INCIDENCE OF TETANUS PER THOUSAND WOUNDED ON WESTERN FRONT. (CUMMINS)

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number of known cases arising on the Western front is thus 2,529. In contrast to this only 20 cases are recorded from all the other theatres of war combined, namely, 3 in Italy, 6 in the Dardanelles, 4 in the Balkans and 7 in Mesopotamia; it may be added that many of these 20 cases were accidental and not due to battle-wounds. These striking facts are in harmony with previous military experience. Tetanus has long been known to occur freely in fighting over soil long cultivated, because the bacillus is derived from animal excreta. In uncultivated and desert countries the risk scarcely arises; only 3 cases of tetanus were recorded in the South African War. In France much of the country over which fighting took place, namely, about the Marne and the Aisne, was known from local veterinary experience to be highly "tetaniferous," but Sieur was unable to ascertain any facts of value as to local distribution of infection from the French tetanus figures, nor could Bruce draw any conclusions on this subject from his analysis of the cases occurring in England.

Incidence.

The following table is drawn up from official figures issued by the War Office. The figures for the wounded are obtained by subtracting from the total casualties the gassed, the sick, the killed and the missing.

	Total No. of wounded.	Recorded cases of tetanus.	Ratio of tetanus per 1,000 wounded.
Western Front	1,710,369	2,529	1·47
All other Theatres of War ..	286,830	20	0·069
Combined total	1,997,199	2,549	1·27

The figure 1·47 represents the average number of cases of tetanus arising in 1,000 men wounded on the Western front during the whole war. Bruce has worked out the corresponding figure month by month, for the cases occurring in home hospitals, and has embodied them in an instructive diagram. Cummins, by combining the B.E.F. and British figures, has constructed a similar diagram, giving a more complete view of the facts, and this diagram is here reproduced.

It will be observed that the monthly ratio exhibits wide fluctuations: it was as high as 8·8 per 1,000 in September

1914, falling to 0·2 in January 1915. It was again high in 1916; in the early months of that year the rise was in part due to the occurrence of tetanus in cases of trench foot; in the later months it was associated with the fighting on the Somme. The low incidence during the closing years of the war conveys an idea of the degree to which tetanus was eventually overcome. Attention must be drawn at this point to the differing conditions in the expeditionary force and in home hospitals. The more lightly wounded could be immediately evacuated to England; the more severe cases were of necessity treated in France, save in times of extreme pressure, and were evacuated later to England as their condition permitted. Thus it came about that the proportion of early and severe cases of tetanus, with their higher mortality, and especially of those complicated by gas gangrene and grave sepsis, was much greater in France than in England. The two sets of statistics differ widely on this account, and it is only when they are combined that the real truth becomes apparent.

Incubation.

The onset of tetanus, taken in days after the infliction of the wound, has been exhibited in curves by Sir David Bruce for home hospitals, and by Sir Wm. Leishman and Colonel Cummins for hospitals in France. The curves rise rapidly to a maximum which occurred on the eighth day in Leishman's earlier series, and on the seventh day in Cummins' later one; in Bruce's curve it is on the ninth day. According to Cummins, the total figures when combined show an actual maximum on the eleventh day. These differences are not large, but a more important difference between the experience abroad and that at home is seen when the proportion of delayed cases is considered. In France only 11 per cent. of the cases occurred after three weeks from reception of the wound; in England no less than 44 per cent. had an incubation period of more than 22 days. One reason for this has already been stated, and the matter will be more fully discussed under serum prophylaxis. The shortest incubation period observed was 18 hours; the longest observed in France was 180 days, in England 2½ years.

Mortality.

The gross case mortality of tetanus for the whole war, calculated from combined B.E.F. and U.K. figures, is exactly 50 per cent. At the beginning of the war it was much

higher than this, at its close much lower, and this fall in mortality was progressive, and seen both in the hospitals in France and at home. The mortality in France was much higher than in home hospitals. The following table exhibits the chief facts for the hospitals in France and England separately.

Country.	Year.	Observer.	Cases.	Deaths.	Mortality per cent.
France ..	1914–15	Leishman	178	140	78·2
,, ..	1916–17	Cummins..	376	252	67·0
,, ..	1918	,, ..	186	110	58·6
England ..	1914	Bruce ..	182	101	55·5
,, ..	1915	,, ..	138	78	56·5
,, ..	1916	,, ..	451	170	37·6
,, ..	1917	,, ..	376	76	20·5
,, ..	1918	,, ..	291	73	26·3
,, ..	1919	,, ..	20	3	15·0

The whole question of case mortality is so closely bound up with that of preventive measures that the significance of the figures in this table will be discussed later.

A summary of the incidence and fatality of tetanus in some of the previous wars is of importance in order that the facts of the war may be seen in their true light. In Napoleon's Egyptian campaign, Larrey gives the mortality in 42 cases of tetanus as 82 per cent. In the American War of the Rebellion the official history gives an incidence of slightly over two per 1,000, with a mortality of 89·3 per cent.; the maximum number of cases occurred on the eighth day after injury, and less than 10 per cent. had an incubation period longer than three weeks. The incidence of tetanus on German wounded in the Franco-German War of 1870–71 was 3·5 per 1,000, and the case mortality was 90 per cent.; the maximum number of cases occurred on the sixth day after the injury, and only 3 per cent. of the cases had an incubation of more than three weeks. As regards civil experience, in the London Hospital from 1887 to 1920 there were 151 cases with a mortality of 70·9 per cent.; in Guy's Hospital the mortality was 84·2 per cent. on 63 cases.

Pathology.

The principles which underlie the prevention and treatment of tetanus depend upon facts which had already been established as to its pathology before the war. The tetanus

bacillus is introduced into a wound in the form of spores contained in dirt contaminated at some former time with animal excreta. The spores germinate only when the conditions of the wound are favourable, and one essential favouring condition is found in the concomitant action of other microbes. Thus septic wounds and wounds presenting extensive tissue laceration are, above all, those giving rise to tetanus. In the absence of favouring conditions the spores fail to germinate, and after a long period may be destroyed, but they may remain alive for many months, and if at any time the conditions become favourable, they may germinate and give rise to delayed tetanus. The toxin produced by the growing bacilli attacks the cells of the central nervous system only by absorption along the motor nerves. It may be absorbed directly along the nerves distributed to the wounded area, but it is also absorbed by the lymph into the blood stream, and in this way may be taken up by motor nerves remote from the wound. For some reason the nervous centres in the pons and medulla are very early affected in the absence of any protection by serum. The disease begins with trismus, and is general from the outset; any local symptoms due to absorption from the wound are masked by the violence of the general disease, and the patient dies as the result of the involvement of the higher centres. When antitoxic serum is administered before the production of toxin has begun, it does not necessarily prevent local absorption of toxin by the motor nerves about the wound, but it neutralises all circulating toxin, so that none is absorbed elsewhere, and the higher nervous centres are shielded so long as sufficient antitoxin is present in the blood. But the protection conferred by antitoxin is a fading one, lasting only a week or two, and in any case there is no proof that it can undo harm already caused to the nerve cells by toxin. Antitoxic serum is thus of far greater value in the prevention than in the cure of tetanus.

Prevention.

The most rational preventive measure is the radical one of total excision of the damaged and infected area at the earliest possible moment, for this at once places the patient out of all danger from tetanus. The treatment of wounds by primary excision was only adopted by surgeons after long experience of less satisfactory methods, and it was not in common use till the spring of 1917. It was devised with several objects, of which the prevention of tetanus was only one, and not

the foremost, but it is certain that it had a pronounced effect upon the incidence of that disease during the closing years of the war. The very favourable figures as to this influence of wound excision, published by Major Gibson, are drawn from data obtained in France at a time when the wounded were being rapidly evacuated to England. They are not wholly borne out by the figures now available, as will be apparent from the diagram of the monthly incidence of tetanus during the war. It is obvious that this radical measure cannot be carried out in all cases. Not only is it precluded by the nature and situation of many wounds, but in times of heavy fighting, and especially of mobile fighting, the practice becomes impossible in all but selected cases. Nevertheless, it remains one of the great surgical lessons of the war that the excision of damaged and infected tissues, when it can be carried out effectively, does in practice prevent tetanus as in theory it ought to do.

It follows from these considerations that the alternative method of administering anti-serum to the wounded cannot be dispensed with. The employment of serum prophylaxis was general after the first month or two of the war, and to this must chiefly be attributed the success attained in combating the disease. The war offered the first opportunity for testing the value of this measure on a really large scale. A striking instance of its utility had, indeed, already been afforded by American experience of tetanus after injuries at " Fourth of July " celebrations, where the number of deaths from tetanus after such injuries, which had been 417 in 1903, had fallen to three in 1914.

When, during August and September 1914, it became evident that cases of tetanus were occurring amongst the wounded with alarming frequency, an order was issued in October 1914 that every wounded man should receive a prophylactic dose of anti-tetanic serum as soon as possible after the injury, the specified dose being 500 U.S.A. units. As this order became operative its effects were soon apparent. As regards cases occurring in home hospitals, Bruce's chart shows a drop from 9 cases per 1,000 wounded in September to 1·4 in December ; nor during the whole war did the figure ever again reach 3 per 1,000 in any month in England, though in France it exceeded it in March and April 1916. Nevertheless, cases of tetanus still occurred in some numbers though of lessened average severity. It was believed that one reason for this was the transient nature of the protection conferred by a single dose of serum.

Following the example of the French, an order was issued in June 1917, that four doses should be given, each of 500 units, at intervals of seven days. There is reason for believing that this order was more effectively carried out in the hospitals overseas than in those at home; in some of the latter it met at first with a good deal of passive opposition. The evidence goes to show that the prolongation of the immune period was of benefit. During the last few months of the war an attempt was made in France to diminish the incidence of tetanus upon the severely wounded by raising the initial, but not the succeeding, doses of serum from 500 to 1,500 units. It cannot be said that any definite improvement was apparent from this change, but the war ended too soon to allow of any certain conclusion on the matter.

The effects of serum prophylaxis must be considered in detail, since it was undoubtedly this practice which so profoundly altered the features of tetanus during the war. A gross ratio of 1·47 cases of tetanus per 1,000 wounded may at first sight seem no very great reduction from the 2 of the American Civil War or the German 3·5 of 1870–71. Such a comparison would be unfair; the conditions of the war of 1914–18 would almost certainly have led to far heavier incidence of tetanus than in any previous experience because of the extreme severity of the wounds inflicted by high explosives and the conditions of mud and dirt under which the fighting was carried on. This is borne out by the high incidence of the disease during the first three months of the war and it is with these three months that later figures should more justly be compared. Had a ratio of 8 cases per 1,000 wounded and a case mortality of 78·2 per cent. been maintained during the war, there would have been 13,683 cases of tetanus on the Western front with 10,700 deaths, in place of 2,529 cases and 1,265 deaths. This saving of 9,435 lives cannot, it is true, be ascribed solely to serum prophylaxis; a part is undoubtedly due to wound excision, but when one remembers the dramatic reduction in tetanus which took place in the closing months of 1914, and that wound excision only became common during the later years of the war, there is little doubt that the chief factor was serum prophylaxis.

The chief effect of serum prophylaxis on the incubation period is seen to lie in the great number of cases with prolonged incubation, a prolongation which became more marked as the prophylaxis became more efficient. Bruce's English figures show that in 1914 the average incubation period was 11·8

days, in 1915, 27·3 days, in 1916, 34 days, in 1917, 48 days, and in 1918–19, 50 days. In France, for reasons already given, the prolongation was much less marked, and even in 1917 the average incubation period was still as low as 13·2 days. That the effect seen was due to the serum is manifest from the fact that in a group of 70 cases in which no serum had been given the incubation period showed a curve identical with that of former wars. The explanation of the delay secured by administering serum, and especially by multiple doses, is sufficiently obvious. It should be added that the lighting up of tetanus after long quiescence and often after complete healing of the wound was frequently due to surgical interference.

In unprotected men and, it must be admitted, in a small number of those who had received anti-toxin, tetanus occurred in its acute classical form with short incubation and high mortality. During the first two months of the war such acute cases were the rule, but, as soon as serum prophylaxis became general, new and unfamiliar types of the disease became increasingly frequent. It may be stated that the signs of general tetanus tended to recede into the background, while in many cases the local signs in the wounded region took on a greatly increased prominence. There arose, in fact, a new form of the disease, born of serum prophylaxis, and known as "local tetanus." This condition, well known in laboratory animals of low susceptibility, such as the cat, had hitherto scarcely been seen in man. Its explanation has been given in the preceding summary of the pathology of tetanus, and it necessitated a revision of the classification of types of the disease current in former days. The new classification which was found most convenient by the Tetanus Committee, together with the percentages of the different types and their respective mortalities in home hospitals, is shown in the following table :—

Classification of Types.	Percentage incidence in home hospitals.	Percentage mortality.
I. Trismus the earliest symptom :		
(*a*) With complete closure of jaws developing within 24 hours after onset of symptoms..	7·3	71·4
(*b*) With complete closure of jaws developing after 24 hours from onset	7·6	50·0
(*c*) With incomplete closure of jaws ..	48·2	24·9
II. Trismus occurring after other symptoms have shown themselves	12·8	18·6
III. General tetanus without trismus	4·9	24·0
IV. Local tetanus	19·2	0·0

This classification was not adopted in France till a late stage of the war, and consequently the corresponding figures are not available on the same scale.

The phenomena of modified tetanus have never before been seen on a large scale, and it is therefore desirable to place a short account of them on record. Professor Andrewes, in the capacity of tetanus inspector for military hospitals in London north of the Thames, had the opportunity of studying between 60 and 70 cases of the disease, which were in all probability a representative series. The following summary of what was observed is based upon notes taken by him at the bedside.

Amongst the cases seen were some of acute general tetanus of classical type; some of these were in men known to be unprotected, others in men as to whom there was doubt whether antitoxin had been given, but in a few instances this type, with its high mortality, occurred in men who had almost certainly received antitoxin, and reference will be made later to this.

In a larger number of cases, although the disease was of acute general type, it lacked the violence of unmodified tetanus, and tended to run a more favourable course. Many of these men recovered under serum treatment, and it was difficult to say whether they did so because of the serum treatment or because the prophylactic dose had somewhat modified the severity of the attack. In some of these cases local spasm about the wound was seen in addition to the general tetanus, but this was not always so. As a rule, such cases fell under Type I (*c*) in the table given above.

In a few instances the general disease was so far modified that its only manifestation was trismus, there being no other sign of tetanus except perhaps some slight exaltation of reflexes. Even local spasm was absent about the wound. On the other hand, in two cases trismus was absent, though the tetanus was otherwise generalized (Type III).

A common type of the disease was one in which the chief symptoms consisted in local spasms, tonic or clonic, in the wounded part, but in which some degree of trismus was also present, and in a few such cases occasional spasms of opisthotonus were seen. Out of 25 cases in which the principal manifestations of tetanus were local, 10 had trismus in some degree. In such instances it must be supposed that the protection was beginning to fade. The trismus usually subsided quickly under serum treatment; the local spasm was much more obstinate.

In 23 per cent. of the series under consideration the tetanic spasm was purely local. This local tetanus assumed two forms; in one the spasm was clonic, in the other tonic, and the two forms were not infrequently combined. The clonic spasms were usually painful; in the tonic cases, which tended to run a more chronic course, pain was not uncommonly absent. In the clonic cases the wounded limb, or, it might be, a stump after amputation, became subject to cramp-like contractions, sometimes recurring every few minutes; such spasms were readily excited by manipulation of the wounded part, as in dressing the injury. These cases were usually amenable to serum treatment, the spasms subsiding in the course of a week or so. In purely tonic cases the part involved became fixed in rigid spasm and might remain so, in spite of treatment, for weeks or even for a month or two. According to the muscles chiefly involved, a limb might be bent or in stiff extension. The spasm might relax under deep anæsthesia, but this was not always so, and it did not relax during sleep. Sometimes the spasm spread slowly to adjacent groups of muscles, as from the arm to the shoulder, or from the thigh to the abdominal muscles. More than this, as protection faded, it was possible for untreated local tetanus to pass gradually into the general disease. Thus an artillery officer, who had a flesh wound of the thigh in which a piece of shrapnel remained embedded, and who received a single prophylactic injection on the day of his wound, was sent to England, where his wound healed perfectly, and he was discharged from hospital quite well. Nine weeks after the wound stiffness of the leg was first noticed, but he returned to duty in France. He did his work with increasing difficulty for a fortnight, and then had to go into hospital again with his leg quite rigid. Trismus now set in, and finally opisthotonus; he was treated with anti-tetanic serum by the intrathecal route and recovered.

Recurrent tetanus was observed in several cases. A man might recover from an attack of tetanus under serum treatment, and yet, the focus of infection remaining and the effect of the serum gradually passing off, symptoms might recur after an interval of six weeks or two months. There was seldom a total disappearance of all rigidity during the interval; the mouth, perhaps, could not be opened to its full extent, or the abdominal muscles remained a little hard; nevertheless all active symptoms had disappeared. Four such instances were seen in this series of cases, and one of them was ultimately fatal.

Cephalic tetanus was rare, but two cases were observed. In the first, an officer with a slight wound on the right temple, paralysis of the frontalis muscle set in suddenly 13 days later, accompanied by unilateral trismus. Spasm spread to the neck and shoulder muscles, but he recovered under serum treatment. In the second, a tiny wound at the outer canthus of the right eye was followed, after 10 days, in spite of two prophylactic doses of serum, by complete right facial palsy, to which right unilateral trismus was soon added. Two days after the onset the patient had a general opisthotonic spasm ; he soon recovered after intrathecal antitoxin, but had transient right oculomotor palsy during convalescence.

The gross mortality of the series of cases from which the preceding account has been compiled was 24 per cent. Many cases have been excluded in which the diagnosis of tetanus could not be made with certainty. It is in no way surprising that in men almost completely protected the manifestations of tetanus should have been so trivial that it was impossible to be certain as to their nature. It is probable that some of the obscure spasms and contractures seen in the later stages of the war were tetanic in origin.

With regard to the effect of serum prophylaxis upon the mortality of tetanus, the figures concerning the case mortality have already been given. They show during the first few months of the war a mortality in British hospitals in France not much below that of former wars ; this mortality exhibited a progressive improvement as the war went on. A similar and even more marked reduction was visible in the data from the hospitals at home, which dealt with cases on the whole less severe. The marked reduction began in 1916, and was thenceforward continuous, except for a slight rise in 1918, coinciding with the heavy mobile fighting of the closing stages of the war. It is impossible to correlate this reduction in mortality with anything but the prophylactic use of serum. The practice of wound excision certainly played an important part in the prevention of tetanus, but Cummins' figures show that its influence in lowering the case mortality of such cases as did occur was not very marked. Bruce has calculated the death rate in 885 cases, grouping them according to the number of prophylactic doses of serum which had been administered. Those who had received only one inoculation had a death rate of 25·1 per cent. ; after two inoculations it was 21·3 per cent. ; after three, 16·5 per cent. ; and after four, 7·1 per cent. He points out that the cases receiving the

larger number of inoculations might be the more chronic and slower cases of the disease, and that the figures are thus not conclusive proof of the value of multiple inoculations; it might be argued with even greater justice that the cases were milder and more chronic because they had received the larger number of injections.

With regard to the occurrence of the disease in spite of the prophylactic use of serum, when tetanus occurred within the first ten days after a prophylactic dose, it was sometimes of the local variety. When it occurred later, it was often general tetanus, reasonably explained by the fading of the protection. But in a certain number of instances acute general tetanus occurred during the period when the patient should have been protected. In some cases the explanation was to be found in the difficulty and delay in rescuing badly wounded men, so that a day or more elapsed before the antitetanic dose could be given. Sometimes, no doubt, the man had not received the dose of serum with which he was credited on his field card; such errors must happen in the stress of work at the front during very heavy fighting, and it is possible that the slight rise in case mortality in 1918 was in part due to such omissions. Nevertheless there was reason for believing that antitoxin did, in a few cases, fail to protect. Tulloch, as the result of experimental work, concludes that when the amount of tissue destruction is sufficiently great, no amount of antitoxin will protect.

It was no very uncommon thing for tetanus to arise after surgical interference with a wound, undertaken for removal of sequestra, rectification of deformity, or other reason. In the 1,458 cases analysed by Bruce, no less than 102 were reported as having thus arisen. This accident might arise at any period, and even when the wound had long been healed. The explanation is that the spores of the bacillus may remain latent and inactive in the tissues for long periods, the secondary operation creating conditions favourable to their germination. Goadby's researches indicate that sequestra are specially liable to harbour such latent organisms. It was consequently urged by the Tetanus Committee that a prophylactic dose of antitoxin should always be given before secondary operative interference with wounds.

Many cases occurred in soldiers during the war from more or less accidental causes; such cases had not, as a rule, received any antitoxin, and they were severe, with high mortality. Two groups of such cases deserve special mention. The first

comprises tetanus arising in the subjects of "trench foot" —a condition which proved a common focus of infection. In France, 13 such cases arose during the last two months of 1916; an order was then issued that antitoxin was to be administered in all cases of trench foot, and during the whole of 1917 only a single case of tetanus arose from this cause. In home hospitals there were 38 instances of tetanus in cases of trench foot; the mortality amongst those who had not been protected by antitoxin was 75 per cent.; after serum prophylaxis was ordered it fell to 16·6 per cent. The second group of cases includes those in which tetanus followed ordinary surgical operations in unwounded men. Amongst the cases arising in home hospitals, one followed operation for varicocele, one after operation for inguinal hernia, two after operations for piles, and five after removal of the appendix. In France, four cases are recorded after appendicectomy, and five after operation for piles. The appendix cases are of peculiar interest since such an accident is almost unheard of in civil practice. Tulloch has succeeded in demonstrating the tetanus bacillus in human fæces in a certain proportion of persons, and it is possible that during the war this proportion may be increased, owing to the swallowing of dirt under the conditions of life in the trenches. In a fatal case of tetanus following appendicectomy, Tulloch demonstrated the bacillus in the stump of the appendix, and in the intestinal contents.

Treatment.

No new method of treatment emerged as the result of war experience. The methods employed were those previously known, and the chief gain to knowledge was an appreciation of their limitations. One remark may be made which applies equally to all forms of treatment; the type of tetanus which chiefly prevailed was, owing to serum prophylaxis, one modified in its severity and presumably with a greater tendency to spontaneous recovery. The favourable results which might be claimed for particular lines of treatment must, to this extent, be discounted when they are compared with those obtained in unprotected cases.

Operative Treatment.—Under this heading are comprised efforts to rid the patient of his focus of infection after symptoms of tetanus have set in, for instance by amputation of a wounded limb or excision of a wound. Although this practice seems at first sight a rational one, experience has shown that it is usually of little avail. At the same time the figures collected by Bruce

from home hospitals suggest that operation under such circumstances may be of possible benefit; he found the mortality in 74 cases thus treated to be 24·3 per cent., as compared with 34·8 per cent. for the total cases treated in England. The Tetanus Committee advised that such operations should not be undertaken till the body was well flooded with antitoxin.

Specific Serum Treatment.—It is generally accepted that the curative properties of antitetanic serum are greatly inferior to its prophylactic power; there is no proof that antitoxin can even gain access to the affected nerve cells, much less that it can dissociate toxin from them. What it can do is to neutralise all circulating toxin and thus check further absorption. The life or death of the patient depends upon whether sufficient toxin to kill him has already been fixed by the nerve cells before antitoxin treatment has commenced. Since this must always be in doubt, antitoxin treatment is always employed, and the differences of opinion which have been expressed during the war have been concerned with the dosage of serum and the route by which it is best administered. A considerable amount of literature has been published on these subjects, and several attempts have been made to decide the questions at issue by an appeal to statistical data. It may be said at once that the fallacies underlying any attempt to prove the value of this or that route, or even the value of large as compared with small doses, are so numerous that no statistical examination of the data available yields any trustworthy conclusions. The reasons for this have been set forth by Bruce, by Cummins, and in particular by Greenwood, and the matter need not be further considered here. The general tendency during the war was to use large or even very large doses of serum, up to 50,000 or 100,000 U.S.A. units, early in the case.

As regards choice of route, the best guides are probably to be sought in what is known of the pathology of the disease, and in the results of animal experiment. For curative purposes, the subcutaneous route would seem condemned on account of slowness of absorption, at least in acute cases in which every hour is of value; in chronic cases and in local tetanus it appears to be an adequate route. The same applies in lesser degree to the intramuscular route, though this was largely used as an adjuvant to more rapid routes. Since the main value of antitoxin lies in neutralizing circulating toxin, the best theoretical route would be the intravenous; the

objection usually raised against it is the danger of anaphylactic shock in men already sensitized by their prophylactic dose of serum. This risk rendered most clinicians reluctant to employ it, but it was successfully used by Professor H. R. Dean of Manchester. He took the precaution of administering the serum under deep chloroform anæsthesia and of 14 severe cases with trismus, to whom 30,000 units of antitoxin were thus given, 13 recovered.

There remains the intrathecal route, which, on the whole, found most favour during the war in acute cases. One argument advanced by its advocates lay in the hope that any toxin in the vicinity of the nerve cells, not yet irretrievably fixed, might thus be most speedily neutralized. A much more convincing reason lies in the results of animal experiment. The work of Park and Nicoll on guinea pigs is well known and reference need only be made here to the brilliant experiments carried out at Oxford by Professor Sherrington at the instance of the Tetanus Committee. He inoculated monkeys with eight times the minimal lethal dose of toxin, waited for tetanus to commence, and then treated them by different routes with 2,000 units of antitoxin. Twenty-five monkeys were treated by each of the four routes; only two recovered with the subcutaneous route, three with the intramuscular, seven with the intravenous, and fourteen with the intrathecal. All the untreated control monkeys died within five days. The Tetanus Committee consequently advised the treatment of acute tetanus in man by an intrathecal dose of 16,000 units of antitoxin at the earliest possible moment, followed by a similar intrathecal dose next day supplemented by intramuscular and subcutaneous doses. They considered that in local tetanus the subcutaneous route was alone needed.

As regards anaphylactic shock, Bruce collected 49 cases from the records of home hospitals during the war, arising after the therapeutic use of serum. Twelve of the cases died. Comparing the different routes of administration in this respect, he calculates that shock followed the intravenous route in 6 per cent. of the cases in which it was employed; the corresponding figures for the intrathecal, the intramuscular and subcutaneous routes were 2 per cent., 1·2 per cent., and 0·2 per cent. respectively. The small subcutaneous dose used in prophylaxis seldom caused shock. Bruce calculates that about 2,000,000 such doses were administered in England during the war; only 11 cases of shock were reported and all recovered. It is probable that many slight cases of shock

were not reported. Serum rashes were not uncommon even after prophylactic doses, and much more so after larger therapeutic doses.

Treatment by Muscular and Nervous Depressants.—Magnesium sulphate was seldom employed on account of the well-known risk attending its intraspinal injection. The carbolic acid treatment was occasionally used, but obtained no vogue. It cannot be said that anything new was learned during the war as to the value of these methods, which were generally regarded as greatly inferior to serum treatment. Such sedatives as morphia and chloral hydrate were, on the other hand, widely administered and proved of undoubted value as adjuvants to other methods.

General Treatment.—The importance of absolute rest and quiet and of securing adequate feeding was emphasized by the Tetanus Committee in a memorandum issued by the War Office in 1917 and circulated for the use of nurses.

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CHAPTER VIII.

TRENCH FOOT.

THE effects of cold in the form of frost-bite or gangrene of the feet have been recorded in armies from early historic times. Xenophon makes various references to the effect of cold in producing these conditions during his perilous march through Armenia. Larrey's description in 1812 of the effects of cold in Napoleon's Russian campaign shows that it was then a familiar condition. In the medical history of the Crimean War of 1854–6 it is recorded that cases of frost-bite and gangrene occurred when the temperature was above freezing point, and especially when there were rain, a cold north-east wind and frost at night. Other factors in this campaign which helped to bring about the disease were lack of opportunities for changing the clothes, tight boots, fatigue, and defective nutrition. Diseases such as scurvy or "fever," were factors in the production of trench foot. Owing to the peculiar conditions of trench warfare, opportunity of movement such as would assist the circulation of the blood was much restricted, and men in the trenches were compelled to remain under cover in the least exposed positions, most frequently at the bottom of a trench half filled with snow or with mud and water up to their knees. Similar cases of frost-bite were described by Davys and Powell Connor among the members of the British Mission to Tibet in 1903; in the Russo-Japanese War in 1904–5, by Macpherson, and again, in the Balkans in 1912, by Max Page.

On the Western Front, during the war of 1914–18, when carrying out reliefs in the trenches, troops had, in the first instance, to march several miles from their billets along wet and muddy roads, and as they approached nearer to the firing line the going became heavier and more trying to the soldier equipped in battle order. The troops arrived thus at the entrance of the communication trench more or less fatigued, and bespattered with mud and wet; and in the days before trench boards were in general use the effort of marching through a long communication trench, sometimes half a mile or more in length, was a feat of endurance which was attended with an immense expenditure of energy. When the men eventually arrived at their destination, after having waded through mud

and water sometimes reaching the waist, they were already wet through, and had then to remain at their stations with little power of movement, owing to the depth of the cold semi-liquid mud which often was at a temperature near freezing point.

During the winter of 1914-15 troops might have to stay in the trenches for weeks at a time, as the duration of the tour of duty varied according to the number of troops available for reliefs. When reinforcements arrived in increasing numbers it became possible to withdraw divisions from the line to areas ten miles or more from the trenches for rest and training. It was then possible for reliefs to be carried out more frequently, and an average tour of duty in the front line would last from 48 to 72 hours, followed by a similar period in support, and another turn in the front line before returning to billets for five or six days in reserve. The men, however, were almost invariably given a liberal supply of good food, and they were warmly clad. Also, even in 1914 it was found possible to provide charcoal fires in braziers in some portions of the line.

As the British front was gradually extended in a southerly direction the nature of the subsoil changed from clay to chalk, with the result that the hardships due to waterlogged trenches were greatly diminished and a much greater degree of protection was attained by the provision of dug-outs which could be constructed, comparatively speaking, without great difficulty in the solid chalk.

In some sectors, owing to the waterlogged state of the soil, the construction of ordinary trenches was impracticable, the difficulties of drainage were insurmountable and the "trenches" were merely crumbling earthworks. During the long spells of wet weather in the winter of 1914–15, the parapets in some low-lying sectors would not stand up and were so flimsy that men were shot through them; and it was not until sufficient material for revetments was available that it became possible to move in the trenches in comparative safety. In the waterlogged country east of Ypres it became necessary to lay down miles of trench-board tracks before it was possible for troops to reach the trenches reasonably dry shod.

Ætiology and Pathology.

Trench foot is generally considered to be caused by cold, wet and the effects of pressure. Bacterial invasion, noted by French Italian and British observers, has been regarded as a secondary infection resulting from the lowered resistance of the tissues.

As the result of clinical observation and experimental work

on animals, Lorrain Smith, Ritchie and Dawson conclude that the essential change consists in damage to the blood vessels. This damage manifests itself by swellings of the endothelial cells in the blood vessels and by the vacuolation of the muscle fibre in the arterial walls. These observers considered it was probable that the ætiological factors concerned in the damaging of the vessels and tissues were complex. The disease may be due on the one hand to the direct effects of cold, or on the other to the starvation of the parts resulting from the vascular constriction and the sluggishness of the circulation generally. With regard to the way in which the condition is brought about in man, they direct special attention to the effects of pressure and constriction; the latter which may be due primarily to the boots may be aggravated by the wearing of two pairs of socks in boots which are not large enough for more than one pair. They noted that in all the cases observed, the lesions were confined to the feet and were specially apt to occur in the part where corns and callosities were common, that is to say, on the inner and outer aspects of the toes, over the joints on the anterior part of the foot and on the heel.

A study of the literature of trench foot clearly indicates the important part played in the causation of the disease by conditions which interfere with the circulation in the feet, such as the long hours spent in an upright or crouching position when on or off duty in the trenches and the want of facilities for rest in the recumbent position. These conditions were unavoidably present in the early days of the campaign; they occurred also in situations where the nature of the ground prevented the construction of dug-outs, or when there had been no time to prepare them, as happened at all times in the case of newly dug trenches.

As an example of the evil effect of cold, wet and conditions affecting the normal circulation of the feet, the war diary of the D.M.S. 1st Army has the following remark on 7th January 1915 :—" Noted during visits to the C.C.S. the grave condition of men coming in with sore feet and found that in most cases boots had never been off or even unlaced for days, sometimes weeks at a time, and that no dry socks were carried." Again, it is recorded that wet boots were worn continuously for periods up to 14 days and the statement is corroborated by others.

A lowering of the hæmoglobin, as estimated by Gower's hæmoglobinometer, in patients suffering from " chilled feet," was noted by Major Gray when in charge of No. 2 Mobile Laboratory. In an average of 25 controls he found the

percentage of hæmoglobin to be 85·5; whereas, in the case of 25 patients who were suffering from chilled feet, the percentage worked out at 77·82. Similar investigations were carried out in No. 5 (Canadian) Mobile Laboratory, but with less definite results.

The universal opinion that trench foot was due to cold and impeded circulation was disputed by Médecins-majors V. Reymond and J. Parisot of the French Army. They claimed to have isolated from the lesions a fungus, which has been identified by Vuillemin as *Scopulariopsis koninjii* and is found in litter, straw and manure, and they maintained that cultures of this mould, inoculated into animals, produced all the symptoms of the condition known as trench foot. According to them the disease was of a fungoid nature, similar to Madura foot, and was caused by contact of the foot with the mud of the trenches. They stated that the affection might be fatal, and that autopsies had shown in some cases alterations in the liver, spleen, lungs, kidneys, and the presence of mycotic germs in the organs. According to them inoculation of bile obtained aseptically produced in animals the characteristic phlyctenules and local gangrene of "trench foot." At a meeting of the Inter-Allied Congress of Hygiene in Paris in November 1919, Dr. Roux, Director of the Pasteur Institute, in opening a discussion on trench foot, stated that the conclusions of Reymond and Parisot were not generally accepted, and that their observations had not been confirmed.

The consensus of opinion, therefore, is that the disease is caused by cold, wet and conditions which impair or interfere with the circulation of the blood.

Incidence.

The greatest wastage from trench foot occurred on the Western Front in France and Flanders, and the affection was also a cause of serious wastage in Gallipoli and Macedonia. In the winter of 1914–15, cases of trench foot were returned under a variety of names, such as "frost-bite," "chilled feet," "effects of exposure," "N.Y.D. feet," or simply as "feet cases." The term "trench foot" does not appear to have been generally adopted until the end of that winter. As might be expected the highest incidence occurred amongst the rank and file of the infantry, the officers suffering to a less extent than their men. Indian troops were affected as well as Europeans both in France and in Gallipoli. The greatest number of cases occurred when troops, with clothing already

thoroughly soaked by heavy rains, subsequently experienced a sudden change to clear weather accompanied by several degrees of frost. New divisions suffered heavily at first through want of experience in dealing with the conditions in the trenches.

According to information supplied by the statistical branch of the Medical Research Council the number of admissions to hospital for frost-bite amongst the British in France and Belgium in 1914 was as follows :—

Month.	*No. of Cases*
August	1
September	1
October	11
November	1,555
December	4,823
	6,391

In December 1914, eight cases diagnosed " trench foot " were also admitted.

In addition to the above, frost-bite was stated to be associated with rheumatism in 306 cases, with myalgia in 69 cases, with bronchitis in 22 cases and with gunshot wounds in 170 cases. The following figures are taken from the diary of the D.M.S. of the First Army. They show the weekly incidence of

Weekly Return of Trench Foot Cases in First Army by Divisions.

Week Ending.	1st Divn.	2nd Divn.	7th Divn.	8th Divn.	Lahore Divn.	Meerut Divn.	Total.
27/12/14 ..	278	75	67	159	—	—	579
3/1/15 ..	201	50	40	165	—	—	456
10/1/15 ..	260	40	96	134	—	—	530
17/1/15 ..	180	48	56	213	—	—	497
24/1/15 ..	30	1	14	173	—	—	218
31/1/15 ..	93	28	47	161	33	45	329
7/2/15 ..	74	27	32	62	34	20	195
14/2/15 ..	30	15	4	21	11	16	70
21/2/15 ..	5	16	34	21	58	—	76
28/2/15 ..	17	9	23	14	36	15	63
Total..	1,168	309	413	1,123	—	—	3,013

The totals given are for British troops only.
The totals from the Indian Divisions are not included.

"foot troubles" in the divisions of that army from December 1914 to February 1915; but, after strong disciplinary measures had been taken in the First Army to prevent the occurrence of trench foot, from the middle of January onwards the disease became more or less negligible at a time when it continued to have a very high incidence in the Second Army in the sectors of the Ypres salient.

War diaries also give some indication of the incidence of foot troubles in Gallipoli during the period 25th November to 20th December 1915, but the number of admissions was actually greater than that recorded, as many diaries merely state that "many" and "several" admissions occurred without quoting figures.

The following are the figures actually shown in the diaries :—

War Diary.	Admissions.	
	Frost-bite.	Trench Foot.
A.D.M.S., 11th Division	667	375
A.D.M.S., 54th Division	49	—
108th Indian F.A.	513	304
2nd Mounted Division	—	625
A.D.M.S., 13th Division	2,130	—
A.D.M.S., 29th Division	200	—
A.D.M.S., 52nd Division	19	—
A.D.M.S., 2nd Australian Division ..	29	—
1/1st Mounted Brigade F.A.	—	17
1/1st S.E. Mounted Brigade F.A... ..	—	1
Totals	3,607	1,322

In Macedonia from 29th November, 1915 to 4th April, 1916, 952 cases of frost-bite and 336 cases of trench foot were admitted to hospital. Of the former, 767 occurred during the week ending 4th December 1915.

Symptoms.

In slight cases the foot may present no abnormal appearance, but is the seat of severe pain and of acute cutaneous hyperæsthesia, which may persist for several weeks; or the whole foot may be swollen, and, although at first cold and so numb as to be practically anæsthetic, it soon becomes very red and hot, presenting the appearance of a large chilblain, to which affection trench foot of this degree is very closely allied. The

D.M.S. of the First Army, on first observing cases of trench foot, described it as " a peculiar form of aggravated chilblain with a painful condition of the feet apparently due to an inflammatory condition of the plantar fascia."

In severe cases the foot is always swollen and the swelling may extend nearly as far as the knee. In these cases the whole foot is absolutely numb at first, but becomes very painful after rest of a day or more in a billet or field ambulance. It was quite common for men to have no feeling of anything wrong with the feet while they were in the trenches, even though the toes were already dead. In many cases of the swollen type blisters occur, and in severe cases these are both large and numerous. In still worse cases the toes may be purple or black, and the same colouring may extend to half or to the whole of the foot. In many such cases, however, the blackness did not indicate deep gangrene, and the great majority of blackened toes could not be regarded as wholly gangrenous ; most of them in fact recovered. In the minority of cases one or more of the toes died, and in a few cases half or the whole of the foot became completely gangrenous. When the toes were dead they often remained dry and shrivelled, but when the foot died the condition was more frequently moist and very foul.

Subjects of trench foot often suffered from tetanus. Bruce drew attention to the importance of the early prophylactic injection of anti-tetanus serum in trench foot, and, when referring to the onset of tetanus in these cases, states, " the disease wastes no time in local manifestations, but bursts out as generalized tetanus and runs an acute and fatal course in 24 to 48 hours."*

Treatment.

In slight cases the only course necessary is to allow the patient to lie down so as to keep the feet elevated. In all cases the feet should be carefully and thoroughly washed with soap and water, followed by an antiseptic lotion, and an injection of anti-tetanus serum must always be given. After being washed the skin should be painted with a 1 per cent. solution of picric acid in spirit. When the feet remain cold and numb they should be frequently rubbed, and in the interval wrapped in cotton wool. If they are red and hot they are often best left exposed, for wrapping in wool only aggravates

* Instructions were issued in December 1916, by the D.G.M.S. on the Western Front for anti-tetanus serum to be given in all cases of trench foot, irrespective of rupture of the skin. Similar instructions were issued by the D.M.S., Macedonia, in the winter of 1915–16.

the pain. Bullæ should be punctured and dressed with some antiseptic. The foot may be enveloped in "ambrine," or other preparations of paraffin wax, if blistering is extensive. Pain is often relieved by aspirin or by salicylates in large doses. In later stages slight cases are much benefited by a course of electrical treatment, especially of the high frequency current, and massage.

Gangrene of toes is best treated by amputation of the toe or toes, after a week or more has been allowed for the circulation of the foot to improve.

In cases of apparent gangrene of the foot it is never right to amputate at once, for in the majority of such cases most of the foot recovers. If the gangrene is dry, it is well to wait for a "line of demarcation," but if moist it is often necessary to amputate earlier. In very few cases is an amputation through the leg required. Syme's amputation can generally be performed, even in the worst cases.

In general, prevention consists in maintaining the men in as fit a condition as possible and in exercising as wide a hygienic control over them as is compatible with the conditions of trench warfare. The particular measures of prevention are summed up in the protection of the feet and legs from mud and wet; keeping them dry, warm and clean; making, in fact, a fine art of the "toilet" of the feet; improving the condition of the trenches, and providing the men in them with hot food. The application of foot powders and foot grease, a variety of which was recommended, was, after all, only an accessory to the toilet of the feet and not essential. The preventive treatment on the above lines are described in detail in the volumes on the "Hygiene of the War," but it may be noted here that the use of rubber boots extending to the top of the thigh was of the greatest value, and also that whatever other precautions might be taken, it was essential not to keep the men too long in deep mud or water at a low temperature.

One of the most important facts established was that even comparatively slight cases, without either blisters or gangrene, took many weeks or months to recover, and it was also noted on many occasions that after an attack of trench foot a man was much more susceptible to a second attack.

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CHAPTER IX.

ANÆSTHESIA.

THE administration of anæsthetics was a subject of interest during the war, especially at the front, and with regard to those methods which experience showed to be the best for badly wounded men. Nitrous oxide, ether, chloroform and ethyl chloride had their special indications, and the ever-increasing possibilities of operating with advantage under local infiltration with novocaine, in combination with general anæsthesia, must also be mentioned. Spinal anæsthesia had a small but definite value in war surgery.

At the commencement of hostilities chloroform was the only anæsthetic supplied at the front and of this there was an abundant supply. Within two or three months ether was also supplied and was usually administered by the open method.

The chief methods used for the administration of the various anæsthetics employed, the factors determining the choice of an anæsthetic and the methods of administration for special cases, are the points which are of most interest and importance.

At first, anæsthetics were administered by one or other of the medical officers of the medical units in army areas, and it was not until 1916 that special anæsthetists were appointed as additional officers on the staffs of the casualty clearing stations. In 1918 these were supplemented by over 200 nursing sisters who had been specially trained during the previous year. Their employment as anæsthetists proved of great service and many of them became very skilful. They also freed a corresponding number of medical officers for duty at the front when there was a serious shortage of the latter.

General Anæsthesia.

Nitrous Oxide.—Nitrous oxide was best administered with a suitable admixture of oxygen. It was also administered without any admixture of oxygen, but its scope of usefulness was considerably less, being almost entirely confined to such operations as could be performed in a few minutes, while the addition of oxygen allowed operations of any length on suitably selected cases. It must however be clearly appreciated

that while gas and oxygen anæsthesia was safe in skilled hands, it was decidedly dangerous if the right methods of administration had not been thoroughly learnt.

Ether.—Ether was best administered as "warm ether vapour" irrespective of the condition of the patient or nature of the operation. Air was passed through ether by means of hand or foot bellows, an efferent tube passing through a thermos flask before delivering the ether-laden air to the patient. The water in the thermos flask should be about 120° F. If much hotter, it tended to cause undue sweating and shallow breathing. A very compact and convenient form of apparatus was designed by Dr. Francis Shipway, which was very extensively used after 1915 in all the clearing stations and hospitals. In this apparatus there were two bottles, one for chloroform and one for ether, a three-way tap allowing air to be blown through the ether, chloroform, or both in varying proportions at will. The induction of anæsthesia might be by the warm vapours, but a common routine was to commence with chloroform or a mixture of chloroform and ether on a lint mask and to continue with the Shipway apparatus, the efferent tube passing through a lint mask or directly into the mouth or nares. Foot bellows were less tiring than hand bellows and left both hands free for any other manipulation that might be necessary. A stream of oxygen might in cases of shock be bubbled through the ether instead of using the air from bellows. Irritating substances were formed if air or oxygen bubbled through ether for more than two hours, and the ether bottle had therefore to be emptied at intervals.

The advantages of warm ether vapour are many; to the patient, diminished loss of body heat, less shock, less secretion, a quicker recovery and less post-operative bronchial irritation and vomiting; to the surgeon, less interference by the anæsthetist in operations about the head and neck, since by the use of the tube the apparatus could be worked at a distance from the site of operation; to the theatre staff in general a much purer atmosphere than when ether is being administered by the open drop method. This is especially marked when acetylene lighting is used. The consumption of ether is less than half that by the open method.

"Open ether" technique does not call for any special description. The temperature inside the mask is usually some 8° to 12° F. lower than when warm ether vapour is used. Intravenous ether anæsthesia did not prove satisfactory for general use.

Chloroform or Mixtures of Chloroform and Ether.—Chloroform was seldom indicated in forward areas except for induction. For this purpose it is useful, since anæsthesia is more rapidly induced than with ether, and chloroform is less liable to stimulate secretion. If chloroform or mixtures of chloroform and ether were indicated they were best administered as warm vapours by the method already described. The open drop method does not require any description.

Ethyl Chloride.—Ethyl chloride was seldom used in the British army. It was best administered by a "closed" method, 5 c.c. being sprayed into a suitable bag which was held over the patient's mouth. Once anæsthesia was established an occasional breath of air was given and a further 2 c.c. of ethyl chloride sprayed into the bag from time to time to maintain anæsthesia. It may also be sprayed on to a lint mask, "open" method, the mask being subsequently covered by the hand or a towel, but this was much more extravagant and the results were less certain. Anæsthesia of more than three to five minutes under ethyl chloride was not advisable. Should the operation be found to take longer than was anticipated it is easy to continue the anæsthesia with ether.

Local Anæsthesia.

Infiltration with Novocaine.—This was in common use, either alone or in combination with nitrous oxide and oxygen.

Spinal Anæsthesia.—Early in the war the administration of stovaine was found to be followed by so great an immediate fall of blood pressure that its employment was entirely abandoned. It proved to be specially dangerous in cases of shock and hæmorrhage. At a later stage of the war the careful intra-spinal use of novocaine was employed with good results in a certain number of cases where amputations through the lower extremities had to be done on patients suffering from shock, but on the whole spinal anæsthesia was not favoured by most surgeons.

Administration of Anæsthetics.

Difficulties in administration peculiar to war patients were singularly few, notwithstanding the fact that patients were rarely "prepared for operation," as in civil life. The lightly wounded robust man would often require a considerable quantity of chloroform or ether to induce anæsthesia, but a normal amount to maintain it. Such men were liable to struggle during the induction period—obviously fighting their

battles over again in their semi-conscious state. This excitement was probably due in part to the unavoidable noise of a busy theatre rather than to any unusual reaction to the anæsthetic.

Patients suffering from shock and hæmorrhage needed very careful handling throughout the anæsthesia, but considering the many desperately ill men who were operated upon and the severity of the operations, the death rate " on the table " was extremely low.

Irritable throats due to cigarette smoking and trench life necessitated, to prevent coughing, a deeper anæsthesia than would otherwise be employed. Apart from the greater prevalence of bronchitis in winter, the fighting man exposed to wet and cold was more prone to an excessive bronchial secretion. Marshall states that: " Autopsies on men who have died of wounds, even when they have had no anæsthetic, commonly show the lung tissue to be congested and excess of secretion in the tubes." A white sticky secretion full of minute air bubbles was occasionally met with. Such patients took chloroform very badly, while ether tended to aggravate the secretion. The remedy would appear to be a judicious admixture of chloroform and ether. Nitrous oxide and oxygen would be the anæsthetic of choice could this condition be diagnosed in advance.

Jaw spasm and stertor were not infrequent in soldiers. When present " Hewitt's artificial airway " proved very useful. This consists of a hollow metal prop to which is attached a suitable curved rubber tube about 4 in. long. The mouth is opened with a gag and the prop is inserted between the incisor teeth, the rubber tube keeping the tongue and soft palate apart. The immediate improvement in the patient's colour, the quieter breathing and better relaxation were remarkable. This simple contrivance should form part of the anæsthetic equipment of front-line units.

Stridor was apt to occur when strongly built men were anæsthetized lying on the chest. It was difficult to control and annoying to the operator, but otherwise would appear to be of little moment.

Choice of an Anæsthetic.

The choice of an anæsthetic and the method of its administration should be determined by the condition of the patient and the nature of the operation. Healthy men with comparatively slight injuries formed a large proportion of the cases

admitted to a casualty clearing station. Nitrous oxide and oxygen in experienced hands might be thought the ideal anæsthetic for such patients, since it fulfilled the three essential conditions—safety, speed and a rapid recovery—the last allowing of immediate evacuation by ambulance train. But the ideal method was not always the practical one. A skilled administrator might not be available, and no one should select nitrous oxide and oxygen without considering the man's physique, habits and lack of preparation. It must always be remembered that strong and healthy men are often resistant to gas and oxygen. It is especially in men weakened by loss of blood or suffering from shock that anæsthesia is easy and that gas and oxygen anæsthesia is specially indicated. The supply and demand of nitrous oxide and oxygen may also have to be considered. The administration of warm ether vapour by the Shipway apparatus was, therefore, the anæsthetic of choice for a large number of lightly wounded men.

In dealing with the more severely wounded, the choice of an anæsthetic is of far greater importance and must be governed by the condition of the patient and the nature of the operation.

Shock and hæmorrhage are commonly associated, and shock is much increased by the administration of chloroform or ether. In such cases, even if the condition of the patient while under ether anæsthesia is satisfactory at the end of the operation, the blood pressure subsequently falls rapidly and the patient dies after some four to eight hours. For these patients gas and oxygen is undoubtedly the best anæsthetic, and may be combined with local infiltration with novocaine. Chloroform should never be employed in cases of shock.

Patients with sepsis, especially with gas gangrene, did not stand an anæsthetic well. Nitrous oxide and oxygen was the best anæsthetic for them, but warm ether vapour was tolerated. Spinal anæsthesia had its advocates. For patients who had recently been exposed to chlorine and other "gas," nitrous oxide and oxygen or warm chloroform vapour with oxygen was better than ether, but other considerations must be taken into account. Fortunately, many patients who had been gassed gave no special trouble on the operating table.

For head operations, local anæsthesia preceded by morphia or omnopon was the best in many cases. If a general anæsthetic is to be given, the convenience of the surgeon must be studied, otherwise almost any method may be selected. Such patients take a full amount of chloroform or ether during the induction period, but require very little

to maintain anæsthesia. Shipway's apparatus is very convenient, the tube being passed through the mask or nares, chloroform or ether or both being used as the surgeon may prefer. Drop methods are usually less convenient to the surgeon because of the proximity of the anæsthetist. If they must be used, it will generally suffice to maintain anæsthesia by dropping ether or chloroform on the towel already covering the patient's head, taking care not to burn the patient's face.

In chest wounds, in the earlier days of the war, when the operation was usually restricted to resection of a portion of a rib and the insertion of a drainage tube for empyema, almost any method of anæsthetizing was satisfactory. Later, a much larger operation was often performed on recently wounded men, and the pleural cavity was explored and the lung wound treated. If the patient was of a placid temperament and sufficiently under the influence of morphia or omnopon, local infiltration combined with the administration of gas and oxygen was used by a few surgeons, but in most cases either chloroform or ether and oxygen by Shipway's method was employed.

In penetrating wounds of the abdomen, local infiltration with novocaine followed by the skilled administration of gas and oxygen gave the most satisfactory results, but failing gas and oxygen and a skilled administrator, warm ether vapour was the best anæsthetic. Such patients should not be given ether by the open method, as they are specially liable to post-operative bronchial catarrh and broncho-pneumonia, and Marshall has pointed out that " with open ether 54 per cent. of our abdominal cases had bronchitis after operation. With warm ether vapour the percentage dropped to 14·7." " These figures were obtained from two comparable series occurring in the same months of two successive years ; only those cases were counted which survived operation more than 48 hours."

In major amputations, the presence of shock, hæmorrhage or gas gangrene will determine the choice of anæsthetic. In all high amputations of the lower extremity nitrous oxide and oxygen provided much the best anæsthetic if properly administered, and should be employed for all major amputations. Very many patients suffering from severe shock who could not have survived the administration of chloroform or ether recovered if the operation was performed under nitrous oxide and oxygen.

For gunshot wounds of the tongue, jaw, maxillary antrum and kindred cases, warm chloroform or ether vapour was very

convenient, the tube being passed down the nose or held in the corner of the mouth as convenience dictated. Should the need for laryngotomy or tracheotomy appear likely, the anæsthetist should ask the surgeon to perform it while it is yet an operation of convenience and not to wait until it has become one of urgency. Chloroform offers a finer control of the depth of anæsthesia and is less likely to stimulate secretion, but it must be used with great care on account of the liability to an obstructed airway in such cases.

Some patients required dressing under an anæsthetic. In these cases preference was always given to nitrous oxide and oxygen since repeated anæsthesias by this method do not harm the patient.

Certain measures apart from the actual administration of the anæsthetic may be considered. Warmth is of the utmost importance to the patient. He should never be stripped of clothing more than is absolutely necessary. Blood transfusion may be required before an operation can be performed, or the blood may be given when the operation is completed and before the patient leaves the table. Solution of gum acacia, 6 per cent. in normal saline solution, is the best substitute for blood, but improvement is less lasting. The effect of subcutaneous or rectal saline is too long delayed to be of any value on the operating table when dealing with severely wounded men.

Oxygen is frequently of the utmost value during anæsthesia. It is a powerful preventive of shock and lessens the amount of chloroform or ether required. It diminishes the amount of oozing at the site of operation, muscular relaxation is the more easily obtained, and post-operative vomiting is certainly lessened. Oxygen also largely mitigates the effects of excessive morphia medication. A gentle stream of oxygen will always suffice and the end of the rubber tube leading from the oxygen cylinder may be inserted under or through the lint mask or the oxygen may be made to bubble through the bottle of the Shipway apparatus.

Hypodermic medication during anæsthesia was generally very disappointing. Camphor* had a temporary stimulating effect. Digitalin, pituitrin, adrenalin, strychnine and brandy were of very doubtful value. The administration of too much morphia in the forward areas was a source of trouble to the anæsthetist. The lightly wounded man usually arrived without any morphia and was thus deprived of a useful adjuvant to

* Camphor 1 part, ether 5 parts, olive oil 4 parts, dose 10 to 20 min. hypodermically.

his anæsthetic. The severely wounded man was liable to be given an excessive amount and this resulted in the subsequent anæsthesia producing cyanosis, shallow breathing and a rigid abdominal wall.

Excessive secretion of mucus and saliva at the end of anæsthesia is an indication for a hypodermic injection of one-fiftieth grain of atropine followed by four-hourly doses of ammonium carbonate and digitalis.

If post-anæsthetic vomiting was severe and did not yield to other measures, it might often be stopped by the intravenous injection of a pint of a 2 per cent. solution of bicarbonate of soda, and this treatment should not be unduly delayed.

In conclusion it may be noted that the art of administering anæsthetics was greatly developed during the war, with immense benefit to both the patient and the surgeon. The increased supply of special apparatus contributed very greatly to this result and the administration of warm ether vapour and of gas and oxygen instead of chloroform saved very many lives.

There is no doubt that these two methods should be mainly employed in all future warfare, and that special training in the administration of gas and oxygen should be arranged so that experienced administrators may never be lacking.

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CHAPTER X.

SURGICAL WORK IN FIELD AMBULANCES.

AT one time or another under the widely varying conditions of the war, sections of field ambulances carried out the duties of every organized medical unit. A complete historical survey of the surgical work which they performed would, therefore, involve reference to practically all the operations which can be performed on war injuries. In general, however, when an ambulance worked in its normal relationship to fighting units and to other medical organizations, the amount of surgical work, using this term in its ordinary sense, which they executed was very limited.

The operative work in field ambulances in all theatres of war was invariably beset by certain difficulties. The nearness to the line of battle imposed unfavourable conditions in regard to space and shelter. The necessity for the rapid evacuation of cases rendered the performance of any serious operation inadvisable, and in any case made observations of the results impossible. Further, definite limitations were set by the amount of equipment and personnel available in these units.

Again, the hazards of war, the nature of the terrain and the different conditions of fighting produced the most remarkably varied demands in the way of surgical work, and imposed on them at the same time special difficulties. For instance, the tent division of a field ambulance often carried out on a small scale the work of a casualty clearing station. In the first month or two of the war, during the pressure of the retreat from Mons, the whole weight of the treatment of the wounded between the front line and the base hospital fell on the field ambulances. Work of this character was also carried out by them in Gallipoli. Such a condition of affairs was exceptional, and was only necessary in the first instance on account of a rapid retreat involving a complete change of base on the coast, and in the second instance on account of the very short communications between the front line and the sea. However needful and efficient the work was on the occasions mentioned, it may be accepted that when the body of troops served by a field ambulance was

fully engaged the normally established unit was not of sufficient size, nor did it possess the adequate equipment to perform such duties properly.

As the war progressed, the medical experience gained led to a crystallization of ideas as to the surgical functions of each type of medical unit. The exact nature of the treatment desirable for the wounded man at the various stages became better defined and the internal organization of various medical units was adapted accordingly.

The experience in the early years of the war emphasized the fact that certain infections were mainly responsible for a high mortality or a slow convalescence in the cases surviving the primary injury. The outstanding and definite advance in the treatment of wounds was concerned with the prevention of these various infections and it was clearly demonstrated at the casualty clearing stations that healing by first intention of the majority of wounds could be brought about by the early and efficient excision of the missile track. The general recognition of this possibility established all the principles which controlled the handling of the wounded man from the time he was hit till he could be transported into surroundings which admitted of the necessary operation being carried out under proper surgical conditions. In general, such conditions were established at the casualty clearing station. The small group of cases in which it was found possible and advisable to carry out operations of a radical character in the field ambulance will be defined below.

The appreciation of the necessity of operations of wound excision exerted an important influence on the treatment of the wounded man during the period he was in the hands of the field ambulance. In order to give such operations their best chance of success it was found that they must be carried out within 24 hours of injury. A corollary to this was that the wounded man should arrive at the operating centre in as good condition as possible. This meant that the development of shock in any form was to be prevented, or limited as far as circumstances permitted. Thus, two important requirements in the handling of the wounded man in the forward area became clearly established, namely, rapid evacuation and the prevention of shock. In relation to the first of these requirements, it had always been recognized that the prompt removal of the wounded from the field of action assisted materially in maintaining the moral of the combatants, also that as a matter of expediency, the rapid evacuation of forward

dressing stations was most desirable in the interests of efficient action on account of their almost invariably limited accommodation.

It thus became generally accepted that the surgical work in ambulance units was of the greatest value when it concerned itself with the handling of the wounded man on the lines indicated above, rather than when elaborate attempts were made to carry out any specialized surgical treatment of individuals. It is true that speedy evacuation, desirable though it was in general, was found to be contra-indicated in certain specific cases. For instance, operation was sometimes undertaken at advanced dressing stations on those cases in which, without it, the journey to the casualty clearing station would have been productive of great shock. Under this heading come proceedings undertaken to check hæmorrhage and the amputation of badly crushed extremities. It was also found that penetrating wounds of the chest were benefited by a rest in the advanced area, and in any such cases in which an open pneumothorax existed suture of the wound at the earliest opportunity was found to be of the greatest importance in improving the general condition of the patient.

In regard to the prevention of shock in general, apart from the question of hæmorrhage, it was found that the avoidance of the loss of body heat and the complete rest of the injured part were the most important factors. The details of the methods employed in the treatment of these various conditions will be considered below under their various headings. They were usually carried out either at an advanced or at a main dressing station.

In general, it may be said that towards the end of the war the advanced dressing station was the centre of surgical work in the forward area and it may, therefore, be worth while to outline the type of structure which best met the requirements of such an establishment in France.

An advanced dressing station was bound to be situated in the medium battery zone and could never be placed far from a main route of approach to the sector of the line which it served. It was, therefore, subject from time to time to heavy shell-fire. Adequate cover could as a rule only be hoped for under conditions of trench warfare. In open warfare, the advanced dressing station had to be placed under such shelter as could be found in a spot consistent with accessibility from the line and the means for rapid evacuation. The accommodation was organized as follows :—A receiving-room with an

adjacent compartment for gassed cases, a dressing-room in direct communication with the receiving-room, and an evacuating waiting-room leading from the dressing-room. A store-room, cookhouse and latrines were conveniently placed and the personnel was accommodated close at hand in dugouts. In Fig. 1, the plan of a satisfactory station of this type organised in a church cellar is shown. The church had been completely demolished above ground by shell-fire, so that the area was not unnecessarily conspicuous to hostile observation.

The importance of good road communication right up to the dressing-station cannot be over-estimated. In Flanders, corduroy roads were usually available or were constructed for

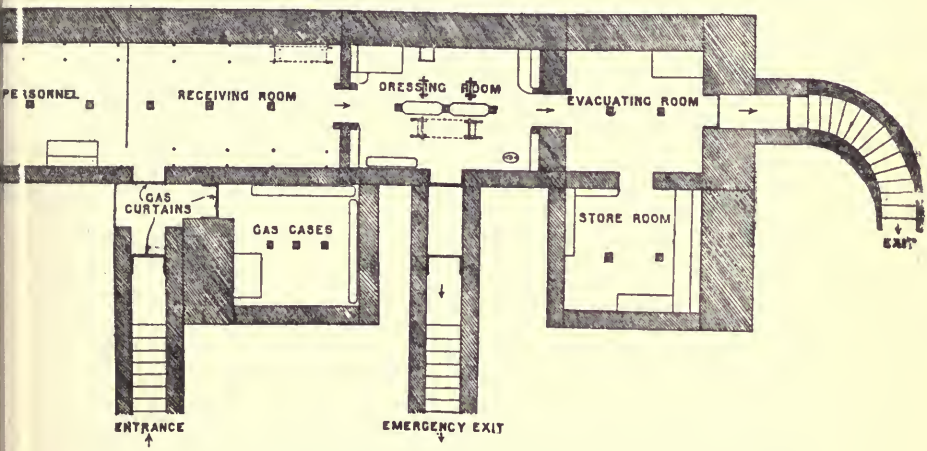

FIG. 1.—Plan of an advanced dressing station organized in a church cellar.

the purpose. Where metalled roads were in fair order they were much more satisfactory as they were less liable to be rendered temporarily impassable to motors by the results of shell-fire.

It must be understood that the elaborately protected advanced dressing station was a development of the later years of stationary warfare. In the earlier years, the convenience of the accommodation was considered rather than defence against high explosives, but, with the great increase in the shelling to which the back area was subjected as the war continued, protection became the point to which most thought was given. In the last phase of the war, the rapid advance reduced hostile gun-fire to a minimum and dressing stations were seldom shell-proof and suffered but few casualties. In

not a few instances during this period the operation tents carried by the field ambulances were used for overflow work in advanced dressing stations and in some cases even large marquees were pitched. When canvas shelter was used, some protection from bomb or shell fragments was secured by sinking the floor of the tent two or three feet and banking up the sides. Such an arrangement called for very careful trenching to avoid flooding in wet weather.

The general principles of the organization of walking-wounded posts and main dressing stations did not differ essentially from those of an advanced dressing station.

Treatment of Shock.

The systematic treatment of shock was not completely developed in the forward areas till 1917. Its occurrence and severity were in all cases influenced by psychical factors. Severe injuries involving the long bones and joints produced the most severe form of primary shock, but appearances which resembled this condition were often produced by a serious or sudden loss of blood. Secondary shock was observed to follow exposure and anxiety, and was seen in its most intense form in starved, fatigued, or nervous men, even though the primary wound was slight. The treatment of shock in field ambulances was directed to combat the factors generally recognized as responsible for its induction.

The checking of all bleeding was found to be of the first importance. In cases in the field where there was a sudden loss of much blood the degree of collapse which ensued was extreme. Obviously, such primary bleeding under the conditions of warfare could seldom be directly controlled. In any such cases which were not at once fatal and had been temporarily controlled in the field by tourniquet, steps were taken at the dressing station to prevent reactionary hæmorrhage. The general treatment of bleeding from large vessels is referred to further on. Cases in which there was oozing from the wound were found to require careful packing; otherwise the recurrent loss of small quantities of blood might produce profound exhaustion before the man reached the casualty clearing station.

The most radical method of dealing with pain, as a factor in shock, was found to be the removal of the damaged tissue, but this procedure was only occasionally practicable in a dressing station. Support and protection of the part from further injury were desirable. Morphia was usually given

hypodermically in a dosage of quarter to half a grain, although some authorities were of the opinion that the adminstration of this drug in any quantity, shortly after the man was wounded, tended to favour the production of acidosis. The conditions in the forward area prevented, in general, the provision of the rest and quiet desirable for these cases.

Loss of body heat was one of the conditions associated with shock, and various attempts were made to keep the wounded man warm in the forward area, although in practice it was often found impossible to prevent a severely wounded man arriving at the dressing station more or less chilled. When possible, his wet clothes were removed and he was treated as described in Chapter III.

It was always recognized that fluid nourishment was an early and pressing need of a wounded man. The administration of hot tea well sweetened with the addition of milk was found to be the most valuable and practical form in which to give fluid by the mouth. The only cases in which it was customarily withheld were those with perforating abdominal injuries. In such cases, some medical officers forbade administration of any fluid by the mouth, and others allowed an ounce or so only, at half-hour intervals. It was generally recognized that if a man could and would take fluid by the mouth, in the forward area, there was seldom reason for administering it by any other route. Administration of fluids by the rectum was not found to be a useful procedure in dressing stations. The administration to be effective necessitated the lower bowel being empty; in any case, the rate of absorption was slow and uncertain.

The subcutaneous infusion of saline solution was at one time employed in some units. This method did not give rapid results and, in general, was found to be useful only when the patient was likely to be left at rest for some hours. Moreover, unless the infusion was effected with care sloughing of the superjacent skin might result later.

Intravenous infusion of fluid was recognized as being the best method when prompt and vigorous measures were urgently required. It was admitted that infusion of any kind by this route should, if possible, be reserved for administration at the casualty clearing station, as it was there that the essential operation was to be performed. Such operation could be carried out in cases suffering from shock with the best chance of success shortly after the first transfusion of fluid had been effected. For this reason, this restorative

procedure was latterly employed at dressing stations only when it was considered that the patient would be otherwise unable to bear the strain of the journey to the casualty clearing station. The storage and transport of sterile fluid presented some difficulties in the forward area and the provision of blood for infusion even greater ones. On a few occasions, the transfusion of citrated blood was carried out, but on account of the technical difficulties referred to, its use did not become generalized. The infusion of gum solution was employed more frequently, and, on the whole, proved the most satisfactory method.

In the early days of the war, it was the common practice to administer subcutaneously stimulant drugs such as strychnine and camphor. Further experience showed that, though such drugs apparently improved a man's condition shortly after administration, their effect was invariably transient and was commonly followed by a relapse. In the latter years of the war, the use of hypodermic stimulants in dressing stations was practically given up. Of stimulants given by the mouth, caffeine contained in tea always held first place.

Treatment of Hæmorrhage.

The surgical treatment of hæmorrhage in the forward area was not so commonly called for as might be expected. The tourniquet was used both by the stretcher-bearers and by the regimental medical officer. At the advanced dressing station it became the rule to remove any tourniquet, and if bleeding persisted to check it by direct surgical treatment. The importance of doing this was made evident by the unfortunate results in those cases in which a tourniquet was left *in situ* more than a few hours; in such instances severe local infection or even massive gangrene of the extremity so treated almost inevitably followed.

The type of hæmorrhage which had to be dealt with was either primary or reactionary, and could be divided into the two main clinical divisions according to whether it came from a main vessel or from the capillaries; the treatment of arterial hæmatomata resulting from arterial injury had also to be considered.

In any case in which there was evidence of damage or laceration of a main vessel in a patient under treatment at the advanced dressing station an operative attempt was made to tie the vessel or, at any rate, to clamp it. The use of a general anaesthetic for the purpose of this procedure was not advised

as it was considered that it prejudiced the further and more radical treatment of the patient's wound when he arrived at the casualty clearing station.

In cases of general oozing it was customary to open up the wound to secure any minor vessels which could be seen and to pack the cavity with dry gauze and apply a firm bandage. Such a procedure was clearly only temporary in nature, and a note on the subject was made on the field medical card for the information of the surgeons at the casualty clearing station.

Arterial hæmatomas, unless rapidly extending, were not treated at the advanced dressing station. A firm dressing was applied, rest for the parts secured by suitable splintage if necessary, and a small dose of morphia given subcutaneously.

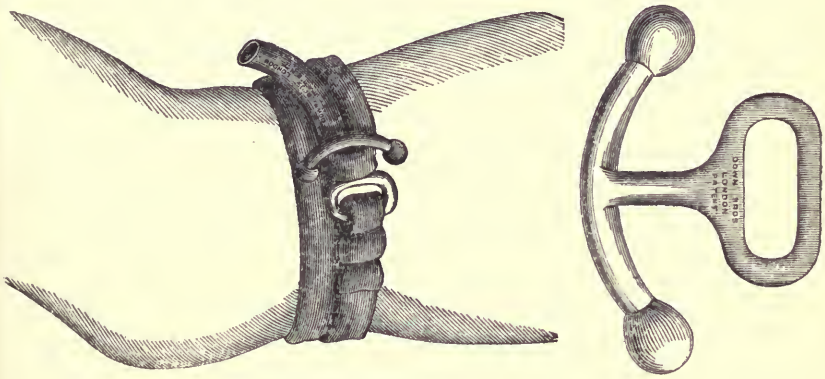

Fig. 2.—Samway's tourniquet with modified anchor catch.

As stated above, the practice of evacuating patients from the forward area with a tourniquet applied was definitely condemned; at the same time there were cases in which as a precautionary measure the tourniquet was loosely put in place to be tightened by the ambulance orderly in case of need. On some occasions the pressure or conditions of work made radical treatment of bleeding at the advanced dressing station impossible, and then the man was evacuated with the tourniquet applied, a special note being put on his label.

The most practical tourniquet for general service in the forward area was found to be the type made from rubber pressure tube and fitted with a Samway's anchor catch (Fig. 2). The screw and webbing type of instrument issued to the stretcher-bearers was found to be unsatisfactory both as regards efficiency and comfort.

Treatment of Wounds in general.

In the early days of the war many efforts were made in the forward area to carry out a prophylactic disinfection of wounds. The procedures adopted varied from the application of tincture of iodine to the exposed wound surface and the surrounding skin to attempts at bringing an antiseptic into contact with the whole wound track, either by squeezing in an antiseptic paste through the aperture of entry, or by syringing the wound with bactericidal fluid. None of these methods was found to be effective in preventing the onset of grave infection in shell wounds otherwise left untreated. Finally it became clearly recognized that all operations for the removal of damaged tissue could be most effectively carried out at the casualty clearing station. It will thus be seen that with the progress of the war the actual direct treatment applied to wounds in field ambulances became limited to the application of a simple protective dressing and adequate splintage; partial attempts at disinfection and repeated changes of dressing had been found to be productive of more harm than good. In fact, in the latter part of the war, the first field dressing applied by the regimental bearers was often deliberately left in place until the patient arrived at the casualty clearing station.

At field ambulances the first injections of anti-tetanic serum were given. Every man who was wounded or who was suffering from severe trench foot received a minimum dose of 500 units. If the wound was extensively lacerated or accompanied by injury to the bone, a primary dose of 1,500 units was given.

First in 1916, and again later, an attempt was made to produce an anti-gas-gangrene serum, on some occasions in combination with anti-tetanic serum; this anti-serum was experimentally given at a few field ambulances, but, so far as evidence was available, did not prove effective in reducing the incidence of the infections.

It can thus categorically be stated that the responsibility of field ambulance units in the direct treatment of wounds was limited to their protection, using the term in its widest sense. The few exceptional cases in which more active treatment was found desirable in the forward area are described below. The protection of a wound was recognized as not limited to the application of a dressing, but as involving all those procedures which procure repose of the injured

part. These included the application of splints, even apart from the presence of fracture, and the gentle handling of the wounded man during transport and dressing.

Treatment of Fractures.

It has always been recognized that the fixation of a broken bone at the earliest possible moment after the injury is important, but it was not until 1915 that it became clearly realized how much the subsequent satisfactory progress of any case of gunshot fracture depended on efficient splinting prior to transport. The appreciation of this fact was chiefly due to the demonstration afforded by the use of the Thomas' knee-splint in the treatment of fractures of the femur. Fractures of this class were, in the early days of the war, fixed in the forward area by some splint of the long outside type. The mortality among patients so treated was extraordinarily high, and those cases which recovered were almost all subject to severe infections and a prolonged convalescence. After the general introduction in the forward area of the Thomas' splint for the treatment of this fracture, the improvement in results was too great not to attract attention. Apart from any advance which had been effected in wound treatment in general, it was clearly shown that an apparatus which fixed a fracture was able largely to prevent shock and to reduce the incidence of infection in the wound.

The actual splints employed in the forward area to fix the various fractures, excluding the more experimental kinds which had temporary or local vogues, were few in number. On mobilization, the supply of splints to a field ambulance was limited to the contents of the standardized field fracture box; this contained a supply of stapled aluminium bars and ribbon, a small quantity of plaster of Paris,and some malleable sheeting. No ready-made splints were issued. It was soon found that, in view of the large number of fractures to be treated, this arrangement was not satisfactory, and the following supply of prepared wooden splints was obtained; for the arm, rectangular splints; for the thigh, Liston long outsides and bracketed modifications; and for the leg, back splints with and without side and foot-pieces.

The type of splint used for the upper extremity was not materially changed until the later stages of the war, when the Thomas' splint adapted to the arm was tried in many units. On the whole, these later introductions were not found to be very satisfactory for transport. They required

very careful adjustment if injurious or, at any rate, uncomfortable pressure in the axillary area was to be avoided; moreover, they were also liable to displacement when the patient was moved about. The Bowlby-Clark hinged internal angular splint proved to be a practicable and safe method of fixation for most injuries of the humerus and elbow at the stage under consideration. (Fig. 3.)

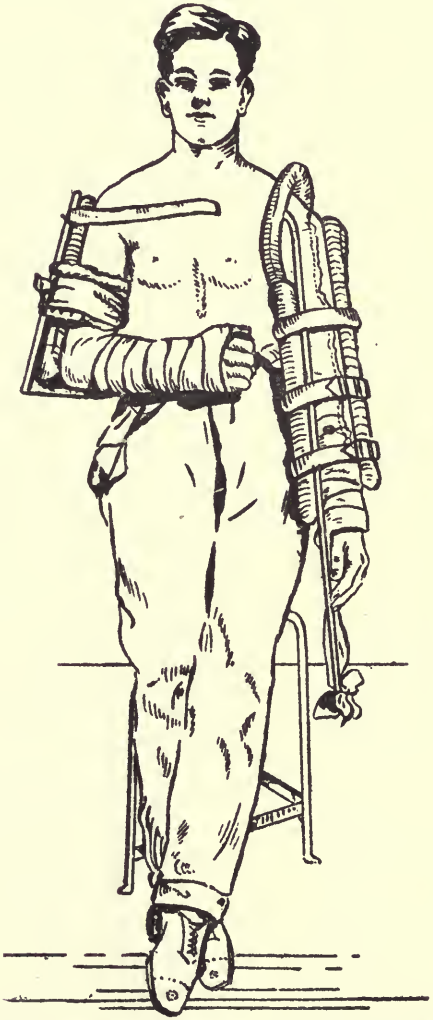

Fig. 3.—Showing the Bowlby-Clark splint applied for fracture of right humerus and Thomas' splint (bent near ring) applied for low fracture of left humerus.

With regard to splintage of the thigh, it soon became clear that the long outside splint left much to be desired ; by its application, extension was seldom efficiently maintained and access to the wound was only possible at the price of displacing the whole splint. Moreover, the control of rotation was poor. The first modification of this splint to be adopted was the splint which had a rectangular foot-piece and a bracketed interruption to leave the wounded area clear of contact with the splint. It was an advance as regards the treatment of compound fractures of the thigh under stationary conditions, and was better for transport purposes than the original Liston. In 1915 a modified Thomas' splint made from the aluminium strips contained in the field fracture box was introduced. This splint was of the skeleton type and allowed proper extension of the limb and free access to the wounded part. Its employment remained limited because the making of each splint took time and some little experience. A splint of this type, the Page, was standardized and made in quantity in malleable iron, and for a time had a certain vogue.

By the end of 1915 the use of Thomas' splint in the treatment of fractures of the femur had become generalized at the base hospitals and at most of the casualty clearing stations. It was not until the end of 1916, however, that it came into common use in field ambulances. Applied as detailed below it was found to be of the greatest value in fixing fractured thighs from the earliest time after injury, and the regular supply of standardized splints of this type became general for all units.

Fractures of the leg below the knee were in the early days fixed at the field ambulance by somewhat casual methods. Later it was generally accepted that the most satisfactory results were obtained by using Barbour's back splint with foot piece, in conjunction with two long side splints. For fractures near or into the knee-joint the use of the Thomas' splint was subsequently introduced. In general, towards the end of the war, it was recognized that all splints should as far as possible be standardized and simple in nature.

In applying splints in the forward area no determined attempt was made to procure complete reduction of the bone fragments to the normal position. Angulation was corrected, but restoration of the normal length of the bone and the control of axial rotation was found to be more suitably left to a later period of the treatment. Some extension was found most

desirable, however, from the earliest period, for the action of extension afforded one of the most efficient methods of securing fixation.

The dangerous results which may arise from the pressure of splints applied soon after injury were in evidence from time to time till the end of the war. In the period immediately after a man was hit and a bone broken there was little reactionary effusion in the limb, but very considerable swelling might develop during the next few hours, either from hæmorrhage or inflammation. Such swelling occurring under a firmly applied splint was liable to produce pressure effects varying in extent from a local pressure sore to complete gangrene of an extremity. On this account it became the rule to cut down and examine at the dressing station all fractures which were causing much pain, or in which the blood circulation in the hand or foot appeared to be impeded.

Fractures of the Humerus.—The splints employed for fixation of the upper arm could be divided into two main types. First, there were those which possessed a crutch or ring taking its purchase on the axillary folds. Splints of this kind permitted the application of extension to the upper arm and were usually of a skeleton form. Jones' modification of the Thomas and Leclercq's were the best-known examples of this kind. Secondly, there were those which had no point of fixation in the axilla and merely supported the arm by being directly bandaged to it. The various forms of angle elbow splints came into this category.

For transport in the period immediately following injury, splints of the first, or crutch type, did not prove satisfactory. It was found that they tended to produce pressure in the axilla, which was usually the source of discomfort and sometimes was sufficiently severe to interfere with the nutrition of the limb.

For fractures of the upper-third of the humerus it was generally agreed that the most satisfactory and comfortable method of fixation was effected by securely bandaging the arm to the body with the elbow semi-flexed and with a wool pad placed in the axilla. As an additional protection and support a gutter of Gooch splinting was applied to the outer side of the limb, extending from the point of the shoulder to just below the elbow. No extension beyond the weight of the limb was required in order to effect satisfactory and safe alignment of these fractures. For the fractures of the middle- and lower-third of the humerus an angular splint was commonly applied

internally with a gutter of Gooch splinting as detailed above. Clark's hinged internal angular splint acted in a similar way and was often used for these cases.

These simple methods showed little change from those adopted at the commencement of the war, and were found to be the most satisfactory. Their advantage lay in the simplicity and ease with which they could be applied, the comfort they afforded the patient, and the infrequency with which they caused pressure sores.

It will be noted that these methods of immobilization of the upper arm were not likely to procure good alignment of the fragments and that injurious pressure on the musculo-spiral or other nerves might be produced by the jagged ends of the fragments. However, in practice, no method of fixation calculated to give really accurate reposition of the fragments was found to be suited to the conditions of work in the forward area.

Fractures of the Fore-arm.—Whether one or both bones were involved, the elbow was usually fixed by means of an internal angular splint, the lower limb of which reached the level of the wrist, the hand tending to fall into the position midway between pronation and supination. An additional gutter splint was usually applied to the back of the fore-arm, being of sufficient length to support the hand. The final results of fractures of this nature were often very poor, both as regards the function of the hand and the union of the bone. It does not, however, appear that these failures should be attributed to inefficient early splintage. Important nerves and tendons are packed into so small a space in the fore-arm that the primary injury alone was almost bound to produce interference with function.

Fractures of the Pelvis.—Special treatment for this type of case was seldom called for in the field ambulance. When the iliac bones were alone involved a firm bandage applied round the pelvis gave sufficient fixation. If the acetabulum was damaged the thigh of the same side was fixed by means of a long outside splint. Cases of injury to the bladder were often not diagnosed at the advanced dressing station, and in any case the treatment of this injury was left to be carried out at the casualty clearing station.

Fractures of the Femur.—The severe and dangerous nature of this injury in war was early impressed upon all medical officers in the army. An historical outline of the appliances put forward for the improvement of the fixation of these fractures

for the purposes of transport has already been given. It is sufficient to repeat that splints of the long outside type were gradually given up in the treatment of these cases, except when the bone was damaged at, or very near, the hip-joint. For the treatment of all other injuries of the femur the Thomas' knee splint established itself as by far the most satisfactory apparatus. On account of its importance and value some points in relation to its use in the forward area may be gone into in detail.

In the later years of the war a systematic method for the application of Thomas' splint for fractures of the femur was laid down by the medical administration of most armies. Many modifications and accessory appliances had been suggested for its use, but the final results were found to depend on a proper appreciation of the main principles of its action in its original form. Splints with very large rings were generally used. The point of counter-fixation was often the perineum and ischio-sacral angle, instead of the tuber ischii. The splint was put on without the patient's clothing or boots being removed. Such a practice was convenient and helped to prevent chilling of the patient during transport; moreover, the foot with the boot on was easily and comfortably fixed in the foot-piece of the splint. As the extension required was destined to remain in action only for the few hours necessary for the transport of the patient to the casualty clearing station adhesive applications were seldom employed. Commonly, the attachment was effected by means of a triangular bandage hitched round the ankle over the boot, a wool pad being interposed. A spring clip to hold the heel of the boot was another convenient method of applying the extension. The pressure produced about the ankle by such appliances, if circumstances led to their remaining in place more than a few hours, was sometimes the source of discomfort and, not infrequently, caused serious pressure sores. In cases in which there was a suspicion of trench foot it was found to be safer to remove the boot and apply an adhesive extension.

It was found to be most satisfactory to hang the splint from an iron suspension bar clipped across the whole width of the stretcher (Fig. 4). When this was not available the end of the splint was propped up on a block of wood or roll of blanket in order to keep the leg free of the stretcher.

Fractures of the Tibia and Fibula.—For those cases of fracture of one or both bones in which the degree or position of the

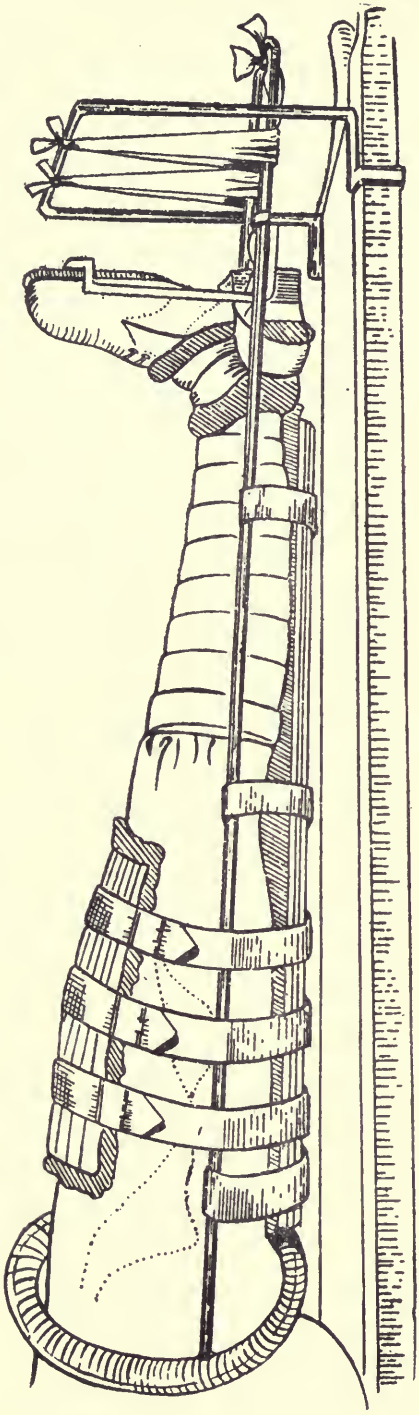

Fig. 4.

injury did not justify immediate amputation, fixation was usually effected by means of a back splint with a foot-piece coupled with two side splints long enough to fix the knee-joint. For fractures into or near the knee-joint a Thomas' knee splint was found to be more effective.

The experience at the base hospitals showed that a large proportion of the cases in which both bones of the leg were broken sooner or later came to amputation. The subsequent history of injuries of this class emphasized the relatively poor results which were to be expected when the fracture was in the lower half of the bone. In these injuries the main nerves and vessels, on account of their anatomical position, were particularly liable to injury by the fragments. Severe infection, muscle gangrene and secondary hæmorrhage were correspondingly common.

In view of these considerations it became recognized that a certain percentage of the worst injuries of this nature were best treated by early amputation before any infection had gained a footing. Such an operation could be conveniently carried out at the field ambulance in quiet periods, though during active operations it was more often left to the casualty clearing station. If the limb was badly smashed, this delay was certainly not in the best interests of the patient, for the shock which such cases developed in course of transport was severe; whereas if early amputation was carried out the incidence of this complication was much reduced.

Injuries of the Joints.

The dangerous effects of infected injuries to a large joint have always been prominent in the mind of the surgeon. The treatment demanded in the field ambulance consisted in the efficient fixation of the joint, and the prompt transfer of the case with a particular note on the field medical card to the casualty clearing station. The large joints were fixed in accordance with the method detailed above for fractures of the long bones entering into the formation of the respective articulations.

Amputations.

In many cases, as just noted, severe fractures of the tibia and fibula are best treated by early amputation. In general, it was not customary to carry out such amputations in the field ambulance or the advanced dressing station unless it was a question of dividing a few remaining struc-

tures with one sweep of the knife. Towards the end of the war the view was taken that a formal, and one which might be expected to be a final, amputation could be undertaken at the advanced dressing station under favourable circumstances. The conditions for which such a course might be considered advisable were, besides fractures of the leg, gross injuries to the knee-joint, and those wounds in which the main vessels and nerves of the limb had been severed. With regard to injuries in the upper extremity, greater conservatism ruled.

Head Injuries.

In the early days of the war it was somewhat generally held that early operation was of benefit to most perforating wounds of the cranium. It soon became clear, however, that the apparent signs of pressure on the brain commonly to be observed after such injuries were in no way relieved by immediate operation. Progressive sub-dural or sub-cranial arterial hæmorrhage of the classical type leading to compression was very rare in cases of penetrating wounds of the cranium. On these grounds, operation on such cases in the forward area was given up.

It was found that head injuries in the advanced dressing station could be roughly classified into two types: first, those severe injuries associated with a thin, rapid pulse, in which there was extensive damage to the brain, and where an early fatal result was to be expected; and secondly, those with a slow, steady pulse, who bore transport well, and could be considered to have a fair chance of recovery. The same principles of wound treatment were applied in dealing with injuries of the head as in the case of the other parts of the body, so far as the nature of the brain substance allowed.

Wounds of the Spine.

The diagnosis of these cases rested, apart from the condition of wounds, on the presence of paraplegia or the interference with control of the bladder function. These signs might be produced by mechanical damage to the cord, by intra-medullary hæmorrhage, or as the result of concussion. In the treatment of these cases, rapid evacuation from the forward area was always recognized as of the first importance, in order that the nursing facilities essential for their survival could be provided. No form of fixation of the spine was

employed beyond that procured by the supine position on the stretcher. The greatest care in padding the sacrum, buttocks and heels was found necessary in order to avoid the formation of pressure sores. The treatment of the retention of urine common in these cases changed during the war. In the earlier days it was customary to advise regular catheterization. Latterly, experience at the base and at home proved that cases which had been systematically catheterized inevitably developed cystitis, and it became customary not to pass a catheter at the field ambulance, but to allow the bladder to fill and overflow as it became over-distended.

Wounds of the Chest.

A considerable proportion of wounds penetrating the chest proved fatal on the field owing to gross injuries of the heart or large vessels. In the surviving cases varying degrees of respiratory distress and cyanosis were the prominent features shortly after injury.

In the advanced dressing station, treatment was directed to providing conditions which might allow the re-establishment of the respiratory and circulatory balance. The two factors necessary to recovery were a reduction in the extent of any pneumothorax and complete physical rest. Suture of the wound margin including the whole thickness down to the fascial layer of the chest wall was found to be the most efficient method of effecting wound closure. Failing this, the wound was packed with gauze which was then fixed with adhesive strapping. After such a procedure had been carried out the air in the pleural cavity was rapidly absorbed, the lung expanded again, and the improvement in oxygen exchange became correspondingly apparent.

Absolute rest in the position giving greatest ease to the patient reduced the demand of the tissues as a whole for oxygen to a minimum, and so gave the hard-worked respiratory and cardiac muscles a chance of reasonable nutrition.

The length of time these cases should be kept at the advanced dressing station before transfer was found to vary considerably. When there was no cyanosis and little dyspnœa, evacuation on the ordinary lines was carried out ; other cases put on one side as moribund made good immediate recoveries after 24 to 48 hours' complete rest. It was generally held that all injuries of the chest were benefited by a quarter or half grain dose of morphia given hypodermically. Direct cardiac stimulants were not found to be of value, though the

general procedures detailed in relation to the treatment of shock were carried out, unless there was reason to expect reactionary hæmorrhage.

Wounds of the Abdomen.

The diagnosis of injury to the abdominal contents, though not always possible shortly after injury, was usually suggested by the position of the wounds and confirmed by the condition of the patient. In many instances, including those of gross injury to the solid viscera, the signs of internal hæmorrhage were the most outstanding features. In other cases, prolapse of the intestine through the wound in the abdominal wall made the need of early operation clear.

In the first few months of the war it was held that cases of perforating abdominal wounds were more likely to recover if they were not operated on except when there was prolapse of some viscus. This attitude resulted from the relatively satisfactory outcome of conservative handling of abdominal wounds in the South African War. It gradually became evident that with the extensive lacerations caused by the pointed bullet and shell fragments of modern warfare, the results of treatment on these lines were disastrous, and series of cases in which early operation was undertaken showed that this method yielded better results.

It was demonstrated that the sooner the operation was carried out after the injury the better the chance of success. The reduction to the minimum of the exposure and fatigue to which the patient was submitted after being hit was found to have a similar favourable influence, and it was on account of these desiderata that during periods of stationary warfare special operating centres devoted entirely to the treatment of abdominal injuries were set up as near the line as practicable. These units were usually established by a section of a field ambulance with the addition of some personnel from a clearing station. From time to time attempts were also made to carry out operative work on abdominal cases in dressing stations. In Gallipoli, one field ambulance systematically operated on all penetrating abdominal wounds, but the final results of these cases were not traced.

In general, attempts to carry out radical abdominal operations in the forward area were not successful; on occasions it was possible to arrange for adequate surgical technique but it was impossible to supply the reasonable quiet

and the skilled nursing, both of which were essential in the after-treatment of the cases. On these grounds it was found better to make a casualty clearing station the operating centre for abdominal cases, as well as for most others.

With the establishment of this routine, the treatment of abdominal injuries in field ambulances became limited to the application of a simple dressing and rapid evacuation to the operating centre. It was found better not to attempt the reduction of herniated viscera, as in most cases of this kind there was extensive internal injury as well, and the mere reduction of prolapse did but partly deal with the case. Especial care was taken to keep the patients warm, and fluid nourishment was only given in small quantity; if the position of the wound or the symptoms suggested an injury of the stomach, fluid was sometimes given subcutaneously. The value of the administration of morphia was a matter upon which differences of opinion existed; it unquestionably rendered the patients more comfortable during the period of transport, but some workers at casualty clearing stations came to the conclusion that cases so dosed were in a less satisfactory state to stand operation than those who had received no morphia. As a matter of practice, most cases of this class received ¼ gr. of morphia at the advanced dressing station, and as long as they did not get a much larger dose they seemed to do fairly well.

Dressings for Field Ambulances.

Both wool and gauze were supplied in large unsterilized packets in the British Army, but in the allied armies in France they were supplied in packets of various sizes ready sterilized. It was only at the end of the war that similar packets were supplied at the British front.

The chief objections to the large packets were that very unnecessary quantities were often used, that an open packet of gauze or wool was liable to become dirty and that in cutting up gauze or wool the material was often contaminated by the hands of orderlies or officers. Much time was saved if the dressings were already cut up.

The conclusions arrived at by most of the surgeons were that it was advisable in the future to issue sterilized dressings to field ambulances ready packed in parcels of three different sizes, and it was believed that such dressings would be safer for wounds and would also prove more economical.

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CHAPTER XI.

THE DEVELOPMENT OF CASUALTY CLEARING STATIONS AND FRONT-LINE SURGERY IN FRANCE.

THE Casualty Clearing Station was the development of a unit which was created in 1907 under the name of "Clearing Hospital," and retained the latter name until January 1915. This unit had not existed in any previous war in which Great Britain was engaged. It was formed as a link between the field ambulance, which was organized after the South African War by combining the old bearer companies and field hospitals into one medical unit, and the lines of communication. It was intended for the temporary reception and care of sick and wounded pending and during evacuation from the front, and its functions were similar to those of the tent division of a field ambulance but on a larger scale.

The staff of a casualty clearing station consisted of a commanding officer, a quartermaster, six medical officers, and 77 N.C.O.'s and other ranks.

No scale of transport was laid down for the units in the 1914 mobilization tables, but a footnote explained that if transport was required it would be furnished under orders of the Inspector-General of Communications. It was calculated that 17 general service wagons or eight 3-ton motor lorries were necessary for transport when the unit was ordered to move by road. Each unit carried 210 stretchers, 200 paillasse cases, 200 bolster cases, 480 sheets, 50 feather pillows, 400 blankets, and sufficient cooking and feeding utensils, medical stores and comforts, and tents for 200 patients, but no bedsteads or mattresses. The surgical equipment was small and included one small operating tent and one operating table. Each unit was provided with a few wooden splints, all of which were too slender to be of much service, and also with some yards of metal splinting material from which it was intended that other splints should be improvised as occasion required. This material was called "aluminium splinting." But the reason of clearing hospitals being supplied on mobilization with this comparatively small equipment was because, being at or in the vicinity of railhead, additional equipment and stores could be more readily obtained from the base than in the case of divisional medical units, and

it was also intended that use should be made of local resources. Before the war, it was an essential part of the scheme for the treatment of the seriously sick and wounded that men should not be retained for treatment in the front-line units, where their presence might create difficulties and might interfere with the movements of the army. The prime duty of the casualty clearing stations was therefore to arrange for the satisfactory evacuation of the wounded and sick rather than for their active treatment.

In the earliest days of the war in France the casualty clearing stations were not in a position to take any great part in either treating or evacuating sick or wounded. At the time of the fighting at Mons and Le Cateau most of them were still packed up and on the railway, and it was not until the battle of the Aisne, in September, that they got to work.

After this battle, when the army moved northward, the casualty clearing stations were able to unpack their stores and to make the best use of their equipment, so that they may be considered to have really embarked on their career during the fighting which extended from Béthune to Ypres. It is interesting to note their positions with relation to the fighting line and the railways. No. 1 was at St. Omer, No. 2 at Bailleul, No. 3 at Ypres, No. 4 at Poperinghe, No. 5 at Hazebrouck, and No. 6 at Béthune. Both Béthune and Ypres were close to the fighting line. Bailleul was about seven miles behind it; Poperinghe about seven miles behind Ypres; while Hazebrouck was over fifteen miles from the front, and St. Omer about twenty-five miles.

All these casualty clearing stations were in buildings, and did not at that time use their tents to any extent, but already they had begun to expand and to take in far more than the 200 for which they were equipped. Thus, at Béthune, the casualty clearing station occupied a very large school for girls, and accommodated more than 600 wounded men; while at St. Omer, the big Jesuit College of St. Joseph housed a similar number, and subsequently many more. All the other units also were forced to expand into neighbouring buildings, so that at Poperinghe No. 4 Casualty Clearing Station spread over three separate buildings, and No. 2 Casualty Clearing Station at Bailleul over two. This expansion meant a great strain on the staffs of only seven medical officers, and, combined with the large numbers of the wounded, quite prevented any surgery being done except in an infinitely small percentage of the total number admitted; but, small though it was, it was sufficient

to show that a front-line hospital might be of very great value in supplementing the work of the field ambulances, and the experience of all the earlier months of the war convinced the surgeons that much more surgery was badly needed at the front. The First Battle of Ypres cost in wounded alone about 13,000 men, and almost all of these depended on the general hospitals on the lines of communication for adequate surgical treatment, whilst very many of them had to be sent at once to England, because of insufficient accommodation on the lines of communication in France. The reason for this was that the sudden move from the Aisne to the Ypres region had made it very difficult to send patients quickly to the hospitals in Paris or Rouen, and want of time had prevented the creation of large enough hospitals at Boulogne or Calais.

It must next be noted that efficient evacuation and treatment by casualty clearing stations were necessarily dependent upon the transport of wounded from the battle-field. When the fighting was transferred to the Aisne, and the line became stabilized, evacuation by train was less difficult, although extremely slow. Motor ambulance cars were employed for the first time in bringing back wounded to railhead on the 20th September 1914, and the first organized motor ambulance convoy was formed on the Aisne at the end of September from ambulance cars sent out by the War Office early in the month. Subsequently other convoys were organized and were at work on the Flanders front after the Expeditionary Force moved there from the Aisne. Thus, on 13th October, wounded, to the number of about 400, from the fighting around Meteren and the Mont des Cats were taken by motor ambulance cars to No. 1 Casualty Clearing Station at St. Omer. At about the same time other motor ambulance cars were bringing the wounded into No. 6 Casualty Clearing Station at Béthune from the area of Festubert, Aubers and Estaires. The numbers passing through the casualty clearing stations during the last week of October were very great, and without the motor ambulance convoys they could not have been brought in so rapidly from the field ambulances. On some days more than a thousand were admitted to a single casualty clearing station, so that all that the small staff could do was to dress the wounds and put the patients into trains as quickly as possible, while matters were made still more difficult by the shelling of Ypres and the consequent removal of No. 3 Casualty Clearing Station from the town. A few days later No. 6 Casualty Clearing Station was shelled in Béthune and had also to retire.

It was during November 1914, when the German attack had been held up and defeated, that the opportunity came for improving the buildings occupied by the various casualty clearing stations. At the same time two very important changes took place, namely, the appointment of a few nursing sisters and the supply of a small number of bedsteads and bedding. These were not only valuable additions in themselves, but they showed clearly the alteration of the original policy that wounded men were not to be retained for treatment at the front. This period, indeed, marked the first important development of a new arrangement by which, ultimately, the wounded were no longer retained in the field ambulances for operative treatment, but were sent on as quickly as possible to the casualty clearing stations.

Early in January 1915, a most important development took place, in that a new and additional surgical equipment was supplied at this time to all casualty clearing stations, and this coincided with the formal approval of the Director-General of more operating work being systematically undertaken by the casualty clearing stations. The consequence was that during January and February large numbers of operations were performed at the front, and in quiet times when no heavy fighting was in progress a large proportion of the wounded were submitted to operation in the casualty clearing stations and were retained for some time before being entrained. Many of the worst cases were head wounds, the result of sniping, for the trenches afforded insufficient protection to both officers and men. But while in quiet times the surgical work could be satisfactorily done to a great extent, as soon as the heavy fighting of Neuve Chapelle, Hill 60, the Second Battle of Ypres, and Festubert developed, the wounded had all to be evacuated to the lines of communication or even to England, and the surgery of the front became again limited to the performance of only the most urgent operations and the application of dressings.

In June 1915, a further increase of equipment for casualty clearing stations was authorized and was quickly supplied,* so that during the rest of that summer the opportunities for good surgical work were greatly improved.

At the Battle of Loos, however, on 25th September, the conditions again resulted in so large a number of wounded in proportion to the supply of casualty clearing stations and surgeons, that only a very small proportion of the wounded

* "Bowlby Outfit No. 2."

could be treated adequately at the front. In the Battle of Neuve Chapelle, in March, there were about 9,256 wounded; and during the months of April and May they amounted to approximately 67,041. The Loos fighting cost 38,161 wounded between 9 a.m. 25th September and 9 a.m. 15th October, and during the whole year 1915 the wounded totalled 206,113.

It must be noted, however, that before the Battle of Loos was fought there had been two other important developments, namely, the erection of the first hutted and tented casualty clearing stations, and the creation of the first "Advanced Operating Centre." Nos. 10 and 17 Casualty Clearing Stations were erected in June and July 1915 at Rémy Siding, near Poperinghe, and an advanced operating centre was established in preparation for the Battle of Loos in the 1st Army at Bac St. Maur, in the area of the 3rd Corps, and at Noeux les Mines in proximity to the battle front. From this time onwards it was the policy of the Army Medical Service to erect casualty clearing stations on open ground, so situated as to be supplied with a railway siding for their own use, and with good road communication towards the front. Advanced operating centres were only erected when it was not possible to place casualty clearing stations sufficiently near the trench line, or when it seemed advisable to supplement the casualty clearing stations in anticipation of heavy fighting.

But, while the developments described above had been taking place, the personnel of the casualty clearing stations had remained unchanged and important reinforcements of medical officers and orderlies had not as yet been supplied until after the commencement of a battle. It must also be remembered that it was only at the end of 1915 that the policy was finally adopted of not doing more operations than could be helped at field ambulances, and of consequently using the casualty clearing stations as front-line hospitals and transmitting wounded to them as quickly as possible. The definite adoption of such a policy was necessarily followed by further changes in the casualty clearing stations.

It had been found by experience that better results were obtained by getting wounded into the casualty clearing stations before any operations were undertaken, and for several reasons. In the first place, it was very advisable that serious cases should be in beds and well nursed; and secondly, it was often much better to move a man before an operation than after it, for in many cases of bad abdominal, chest or head wounds

movement directly after operation was very dangerous to life. Arrangements for sterilizing instruments, gowns, etc., were also much more difficult at field ambulances, and it was more difficult to obtain the necessary quietude and freedom from disturbance. It may, therefore, be concluded that after the end of 1915 the bulk of the surgical work at the front was finally transferred from the field ambulances to the casualty clearing stations, and continued to be so during the rest of the war.

The necessary result of this transference of surgery was the appointment and training of suitable surgeons, and, whereas at first a single "surgical specialist" was allotted to each casualty clearing station, a "second surgeon" was now appointed as well. It was also very necessary that when any surgeon showed great surgical ability and aptitude he should not be moved from his unit without sufficient cause, for the right sort of man would not only improve his own work by experience but would also help to train other members of the staff, and would organize and develop, in conjunction with his commanding officer, the whole surgical routine of his unit. It thus happened that there grew up a body of young surgeons who, guided by the advice of the consulting surgeons of their respective armies, gradually developed a "surgery of the front," based upon the principles of good civilian surgery; and, as time went on, one heard less and less that the difficulties of the war conditions were sufficient to excuse poor technique or inadequate asepsis.

During the earlier part of 1916 many of the new casualty clearing stations were greatly enlarged, some of them being entirely hutted, but others partly in tents. As early as October 1915, it had been agreed that the small operating tent should be given up, and its place taken by a hut of 60 feet in length and 20 feet in width. This was subsequently the regulation supply on the entire front. It gave good room for four operating tables and their equipment.

At the beginning of 1916 a "Memorandum on Wounds" was published by the War Office, and issued to all medical officers. It had been written by some of the consulting surgeons and physicians in France, on the instructions of the Director-General of the British Expeditionary Force, and it formulated the conclusions as to some general principles of treatment agreed to in 1915.* The distribution of the memorandum was of

* An enlarged edition was issued in 1917 under the title of "Injuries and Diseases of War."

great assistance in establishing definite methods, and it enabled general instructions to be easily circulated at the front.

It was in accordance with this that the following memorandum, drawn up by the advising consulting surgeon for the front areas, was issued on the 27th April 1916, by the D.M.S. Fourth Army. It gives a good general idea of the methods which were then being adopted everywhere, and shows what progress had been made at that time in the arrangements for treating wounded men.

"TREATMENT OF WOUNDS."

"The attention of all R.A.M.C. officers is called to the memorandum—'Treatment of Injuries in War.'

All D.Ds.M.S., A.Ds.M.S. and Commanders of Medical Units should ensure that all medical officers serving under them (more especially those who have come from home) are in possession of the book, and that, as far as possible, the treatment advocated therein is carried out.

Special stress should be laid upon the following points:—

(1) Only operations of emergency should be performed in field ambulances, but the following exceptions should be noted:—

(*a*) Completely smashed limbs should be removed, and the patients retained for at least a day before being sent to a casualty clearing station.

(*b*) Hæmorrhage should be arrested by ligature of bleeding vessels whenever possible. If this is not possible, then plugging and direct pressure on the wound itself should be resorted to; and patients should never be sent down with elastic tourniquets on their limbs. Tourniquets have often caused gangrene, and always cause very severe pain.

(2) Abdominal wounds require treatment at a casualty clearing station as early as possible, and even if penetration is doubtful, should be at once sent on by special motor ambulance. All wounds of the loins and buttocks which are associated with abdominal pains are probably penetrating wounds of the abdominal cavity, and should be treated as such. Operations on the abdomen are to be done at the casualty clearing stations, or at special emergency hospitals.

(3) Chest wounds penetrating the lungs, and having large openings admitting the free passage of blood and air, should be treated by cleansing the wound, and plugging it with sterile gauze, and applying rubber plaster so as to close it hermetically. If not so treated, the patients often die of hæmorrhage.

(4) In cases of fractures of the extremities, splints should always be applied before the limb is bandaged. All wounds of joints should also be splinted.

(5) The application of iodine to the skin, followed by the use of cyanide gauze, results in severe blistering, and this combination should be avoided.

(6) Neither amputation wounds nor any other wounds should be closed by sutures. They should be left completely open.

(7) All severe cases requiring early treatment at a casualty clearing station should be at once sent there by a special motor ambulance direct from field ambulances. They should not be kept waiting for the regular convoys."

The preparations for the offensive on the Somme in July 1916 gave the first opportunity of arranging for surgery on a

large scale in heavy fighting, and fourteen casualty clearing stations and one advanced operating centre with forty beds were supplied to the Fourth Army, which was the chief seat of attack, apart from the casualty clearing stations in the adjacent Third Army. Many of these casualty clearing stations were large enough to accommodate 1,000 patients, and on the night of 1st July several of them accommodated twelve or thirteen hundred.

In order to deal with the great numbers of wounded expected, the staff of medical officers of the casualty clearing stations had all been more than doubled before the battle began, and additional nursing sisters had also been supplied beforehand. All of these were further increased as soon as the numbers of wounded were realized. They were more numerous than in any previous battle, for on the first day about 14,400 men were admitted into 13 clearing stations of the Fourth Army, on the second day 13,806, and on the third day 8,793. The difficulties of adequately treating such large numbers were increased by the fact that during the first twenty-four hours of the battle a sufficient number of ambulance trains had not come up to relieve the congestion in the casualty clearing stations. Yet many hundred operations were performed even when the stress was greatest, and in the four and a half months during which the battle lasted more than 30,000 operations were performed in the casualty clearing stations and the advanced operating centre of the Fourth and Fifth Armies alone. It should further be noted that, in anticipation of much operating, very large numbers of additional surgical instruments and equipment of all sorts had been supplied, for without these the additional surgeons would have been of comparatively little help. The total number of wounded during the Battle of the Somme from 1st July to 17th November was approximately 318,408, of whom over 124,796 were treated in the month of July alone. In the whole year 1916 the number of wounded was over 450,887.

It has already been mentioned that the casualty clearing stations had been greatly enlarged for the Somme offensive, and it was at this time that certain general principles began to be evolved which ultimately resulted in the standardization of a definite system for the distribution and treatment of the wounded. In accordance with this, a casualty clearing station comprised :—

(1) A general admission tent or hut in which the necessary particulars were entered as each patient arrived.

(2) A tent for the dressing of walking patients.
(3) A tent for the dressing of lying-down patients.
(4) A pre-operation tent.
(5) A resuscitation tent.
(6) Tents where patients might be kept for treatment.
(7) Tents where patients for evacuation were placed.

In any casualty clearing station so planned, the patient was given hot drink of some kind on arrival, generally tea, and, if a walking case with a slight wound, he would be passed through the dressing tent straight to the evacuation area, and thence to the train. If an operation was advised his dirty clothes were removed in the pre-operation ward, and he was if possible dressed in clean pyjamas before being taken to the operating theatre. If he was suffering from shock or exposure he was taken first to the resuscitation ward, and after operation he was either put in bed to be retained, or on a stretcher for evacuation.

X-ray Work in Casualty Clearing Stations.

As it had not been foreseen that much, if any, operation work would be done in casualty clearing stations, no X-ray outfits were originally supplied, but early in January 1915, mobile X-ray vehicles were allotted, one to the First and one to the Second Army. Later on, as the surgery of the front increased, additional mobile and fixed sets were supplied, and in 1917 many of the casualty clearing stations had their own apparatus. The value of the mobile X-ray vehicles varied greatly, and while some of them were really mobile, others moved with difficulty or sometimes only moved at the expense of many breakages. As time went on, it became evident that the ideal was for each casualty clearing station to be supplied with a lorry which carried all the X-ray apparatus arranged so that the power could be supplied from the lorry. Experience also showed that it was necessary to provide suitable " X-ray " huts instead of tents, as without huts the results obtained were never satisfactory. It was soon evident that X-rays were of the very greatest value at the front, and were if anything even more important there than at the base hospitals. In many cases their use obviated an exploratory operation, while in others they supplied the information without which no operation could be performed. They undoubtedly constituted a very essential part of the equipment of all casualty clearing stations.

In some cases where there was a group of casualty clearing stations close to each other, a single power station was erected

for the supply of them all. Thus at Tincourt in 1917 the X-rays of three casualty clearing stations were run from a single installation. But, as more and more demands were made for the use of X-rays at the front, it became evident that the officer in charge could not do the work unaided, and a skilled N.C.O. was added to the original staff. It also appeared that, just as it was necessary to supply surgical reinforcements for heavy fighting, it was necessary in addition to obtain the services of additional X-ray specialists. The supply of X-ray equipment and of special officers was never equal to the demand, for while the apparatus itself could be readily obtained, difficulties in supplying suitable engines remained to the very end of the war.

The Grouping of Casualty Clearing Stations.

As soon as the first grouped casualty clearing stations were established at Rémy Siding in 1915, it became possible to arrange that they should be on duty " turn and turn about," and this meant that in so-called " quiet times " each was taking in during alternate periods of twenty-four hours. In this way each unit was able to get through the necessary work of treating the patients already admitted without being disturbed by the arrival of fresh wounded, and the whole staff had a period of rest from fresh admissions. From that time onwards the system of grouping two or more casualty clearing stations was adopted as a general principle, and by this arrangement it was easy to provide for a single railway siding or a single water supply for all the casualty clearing stations of any one group. This was a saving of great importance.

During heavy fighting the group system was also of great practical value in another way, for it was then arranged that each casualty clearing station of a group should take in wounded, not for a certain fixed period but up to a certain number, and when this number was reached the motor ambulances arriving with wounded were " switched off " to the next casualty clearing station, until it also had received the allotted number. This arrangement was first put into practice for groups in the Somme fighting in 1916,* but afterwards became universal. The number that should be taken in before " switching off " necessarily varied in proportion to the pressure and to the number of surgeons at work, but whereas at first as many as 400 were admitted before another casualty clearing station took on the work, the longer the war lasted the more the

* The system had actually been in practice in the First Army during the Battle of Loos in 1915, but before the grouping of casualty clearing stations.

numbers tended to be reduced, so that 150 or 200 became a standard, and one severe case was often by arrangement counted as the equivalent of two patients able to walk. It was also found that when large numbers of wounded were arriving at the beginning of heavy fighting it was best to take in only 100 at first, or even less, for in this way the staffs of two or more casualty clearing stations got quickly to work instead of being kept waiting in idleness while the first casualty clearing station on duty took in a large number.

The Work of Consulting Surgeons in Casualty Clearing Stations.

The development of the surgery of the casualty clearing stations was largely the work of the consulting surgeons at the front. In September 1914, two consulting surgeons were sent to France, and after the middle of October one of them, Sir George Makins, remained at Boulogne and the other, Sir Anthony Bowlby, began to visit the casualty clearing stations. It was not until May 1915, when the British Expeditionary Force had been divided into two armies, that a second consultant was appointed to the front, but from that time onwards a consulting surgeon was appointed to each of the armies, and each of these held the rank of Colonel A.M.S. or, later on, of Surgeon-General.

Early in 1916 the Director-General in France decided that in order to co-ordinate the surgical work of the four armies now in the field, it had become advisable to have an additional consulting surgeon, and Sir Anthony Bowlby was appointed with the title of "Advising Consulting Surgeon, British Armies in France," and was thenceforth on the staff of the Director-General, with the rank of Surgeon-General.*

The work of the consulting surgeon at the front underwent very great changes as the war progressed. At first he was entirely utilized for the purpose of giving advice on certain wounded men or of doing an operation, and he visited the casualty clearing stations in order to see patients for whom his opinion was sought. Subsequently he also made suggestions on the equipment of the casualty clearing stations, and his advice was invited on various methods of wound treatment. At this period, however, it was no part of his duties to make arrangements for the surgical treatment of large numbers of

* Sir George Makins was at the same time appointed "Advising Consulting Surgeon for the Lines of Communications" also with the rank of Surgeon-General.

wounded, nor was he consulted on the surgical arrangements for proposed offensives. His responsibilities were limited to giving professional advice. It was not until the Somme offensive was in preparation in 1916 that authority was given to the advising consulting surgeon to arrange with the D.M.S. of the Fourth Army for the necessary preparations to be made for surgical operations to be done in the casualty clearing stations on a large scale, and for the consequent increase of equipment and personnel.

From that time onward the rôle of the consulting surgeon was changed, and he took his place on the staff of his Army D.M.S. and became responsible as an adviser in all arrangements for the surgical preparations in proposed offensives, for the surgical equipment and work in casualty clearing stations, and for the appointment of surgical specialists. As experience of front-line surgery grew, it became evident that good work required the co-operation of a responsible surgeon with the D.M.S. of each Army, and this in turn led to the Director-General appointing a committee composed of consultants and administrative officers, and also calling from time to time meetings of all the consulting physicians and surgeons.

The consulting surgeon in each army also gave surgical instruction to the field ambulance personnel on such matters as the use of new splints, on new proposals for the treatment of shock, and on the various methods of intravenous infusion.

It was the duty of the advising consulting surgeon to visit all casualty clearing stations and to co-ordinate the surgical work of all the different armies, to supply information of new methods of treatment, and to bring to the notice of the Director-General any surgical matter of which he ought to be informed. He also advised on the appointments of surgical specialists to the casualty clearing stations, and as to the composition of the "surgical teams" which as occasion arose were sent as reinforcements, either from one army to another, or from the lines of communication units to the front.

The Battle of the Somme, in 1916, may be said to have fully justified all that had been agreed upon with regard to the necessity of good front-line surgery and the early operative treatment of the wounded man. It was, however, very evident that as yet only a beginning had been made, and that much more was required. Consequently, on 28th February 1917, an important consultation took place between the Director-General and the consulting surgeons of the front, to consider

a memorandum by the advising consulting surgeon on the "Treatment of Wounds at the Casualty Clearing Stations," and it was decided—

(1) That early operation on wounds requiring it should be done at the casualty clearing stations whenever possible.

(2) That for heavy fighting the staffs of casualty clearing stations should be reinforced to a minimum of fourteen medical officers and fifteen nurses.

(3) That when surgeons were sent from one casualty clearing station to another for reinforcement they should take with them, so as to constitute a "surgical team," an assistant, an anæsthetist, and a nursing sister of experience in operative work.

(4) That beds should be provided for at least 10 per cent. of the total accommodation in each casualty clearing station.

(5) That when only one group of casualty clearing stations in any army was heavily worked reinforcements of medical officers should be sent by the D.M.S., in motor ambulances from his other casualty clearing stations, even if for only a few hours.

(6) That gas and oxygen and suitable apparatus for its administration should be supplied in large quantities for anæsthetic purposes.

The above conclusions arrived at by this conference were of the greatest importance to the surgery of the front, and may be said to mark an era in the development of military surgery in France, for they definitely approved in principle of the arrangements recently evolved during the Somme offensive, while they also permitted a further expansion of the casualty clearing stations by officially providing a percentage of beds and an increase in the staffs of medical officers and nursing sisters.

In addition to this, the initiation of the system of reinforcement by definite "surgical teams" proved to be of the utmost importance to the further development of military surgery in the ensuing years of the war, and from this time onward the custom of reinforcements by surgical teams within each of the five armies, apart from those sent by General Headquarters, was carried out at the discretion of the D.M.S. concerned. Consequently, whenever only a small proportion of the casualty clearing stations of any army was heavily worked, it was very easy to send surgical teams from neighbouring casualty clearing stations by motor ambulance car within an hour or two.

The year 1917 opened with British attacks in the Somme region on a limited scale, but on 9th April the Battle of Vimy and Arras resulted in heavy casualties in the First and Third Armies. The rush of wounded had been fully anticipated and, in accordance with the arrangements already authorized, all the casualty clearing stations concerned were prepared with increased staffs and equipment of all kinds. The result was that a larger proportion of the wounded were passed through the operating theatres than ever before, and that an average of about 20 per cent. were operated upon in the casualty clearing stations, although between 9th April and 31st May the total wounded in the First, Third and Fifth Armies amounted to over 90,000, of whom over 17,000 were treated in the first three days of the battle. The results of this early surgery were shown at the general hospitals by a great diminution in the occurrence of gas gangrene, sepsis and secondary hæmorrhage, and a general improvement in the well-being of the patients.

On 7th June the Battle of Messines was fought by the Second Army, and here, owing to the more limited objective, a larger proportion of casualty clearing stations was available and also larger staffs. On the first day 10,434 wounded were treated in eleven casualty clearing stations and one small advanced operating centre, and in three days a total of 16,238 wounded passed through the same units.* Over 2,400 of these were operated upon at once, with the result that the general hospitals reported only one-half per cent. of gas gangrene, very few amputations, and a very low death-rate.

At the end of July Hill 70 at Loos was captured by the Canadians, and the consulting surgeon of the First Army reported that of the 4,000 wounded 20 per cent. were operated upon by thirty surgical teams utilizing twenty-three operating tables, and he compared this with 13,910 wounded on the first day of the Battle of Loos in September 1915, when there were only sixteen teams and sixteen tables.

Preparations were begun early in anticipation of the fighting in the Ypres Salient, and in view of the experience gained at Arras and Messines, and of the unanimous reports of the greatly improved conditions of the wounded in units on the lines of communication, the advising consulting surgeon at General Headquarters proposed that—

* The actual number of wounded in all divisions of the Second Army was considerably higher, namely, 17,404, with 1,386 of the enemy in addition.

(1) Each casualty clearing station should provide arrangements for eight operating tables, instead of four as previously.
(2) Six surgical teams should be supplied to each casualty clearing station, and should each include an orderly used to operating theatre work.
(3) Extra medical officers should be supplied to bring the total medical officers of each casualty clearing station up to a minimum of twenty-four.
(4) Twenty additional orderlies should be allotted to each casualty clearing station, as well as additional stretcher bearers.
(5) The number of nursing sisters should be increased to twenty-five.
(6) Each casualty clearing station should be supplied with additional equipment of surgical instruments, operating tables, gowns, towels and other articles in proportion to the increase of the staff and according to schedules supplied for the purpose.

All this was agreed to, but as it was not possible to supply enough surgical teams from the casualty clearing stations of other armies alone, thirty-two teams were drawn from the general and stationary hospitals. It must also be noted that for the first time a number of surgeons from the United States and from the British Dominions were included in these teams. The supply of all these surgeons by the lines of communication was only made possible by the fact that the more operating work was done at the front the less there was to do at the base. The pendulum had now swung so far over that not only were operations not confined to the general hospitals as in early days, but far more were performed in the casualty clearing stations than on the lines of communication. At the beginning of the battle most of the fighting was done by the Fifth Army, but in the later stages the Second Army took the chief part.

The attack began on 31st July, and from that date to 13th November 1917, the total wounded in the Third Battle of Ypres were :—

	Second Army.	*Fifth Army.*
August	5,631 ..	47,704
September	26,658 ..	22,504
October	48,212 ..	29,592
November	13,216 ..	3,600
Total	93,717 ..	103,400
Grand Total	197,117.	

In the Fifth Army the casualty clearing stations dealt with 16,088 wounded in the first two days of the fight, and in the first three days 3,091 wounded were operated upon out of a total of 15,430 men. The percentage of operations to total wounded was 10·5 per cent. on the first day, 20·5 per cent. on the second day, and 30·0 per cent. on the third day.

The reports from the Second Army were much the same, and for the two armies together, during the whole period of three and a half months ending on 16th November, in all 61,225 operations were performed on 199,664 patients, *i.e.*, more than 30 per cent. of the wounded passed through the operating theatres, with the result that comparatively few operations required to be performed at the general hospitals. The latter also reported that there was a welcome absence of surgical complications and a very low death-rate. The condition of the wounded from a battle of the same magnitude had never been so good.

The heavy fighting of 1917 terminated with the attack and counter-attack of Cambrai in the Third Army area in the last ten days of November, but, owing to rapid reinforcements from casualty clearing stations in the neighbourhood, the casualty clearing stations of the Third Army were well able to deal thoroughly with 25,000 casualties in ten days, notwithstanding the surprise of the German attack on 30th November.

During 1917, the casualty clearing station work had developed out of all proportion as compared with previous periods, and it will be seen later that in the last year of the war, 1918, it was not found possible to increase the surgical staffs further, because the whole front was simultaneously so much engaged at that period that such large staffs as those employed during the Third Battle of Ypres could not be supplied.

It was, however, during the year 1917 that very many important surgical improvements were so established that in 1918 they had become generally adopted. Wounds which had formerly been merely opened and drained were now submitted to careful operation and excision. Some of them were being treated by the Carrel method of irrigation, but in an increasing number of cases they were closed by "primary" or "secondary" suture, as described on p. 244. The surgery of various special regions had been very greatly improved, so that operations on the abdomen, which were performed without great success in 1915, and by only a few surgeons, were now performed everywhere with gratifying results. Wounds of the lung were subjected to surgical treatment in many cases, and operations

for injuries of the head gave a much lower death-rate. Wounds of the joints, and especially of the knee, were carefully closed after excision of damaged tissues, and drainage of them was never employed where it could possibly be avoided. The administration of anæsthetics had developed the use of the "Shipway" warm ether apparatus, and gas and oxygen had proved so invaluable in cases of shock that, where it could be obtained, it was always employed in preference to all other anæsthetics.

At this time also the nursing sisters were trained in the administration of anæsthetics, because the shortage of medical officers had gravely increased. The experiment was a complete success, and more than a hundred medical officers were freed for other duties. During the fighting in the Ypres salient transfusion of blood was first employed on a large scale, and proved of the greatest value. It was given either direct through a paraffin-coated glass receiver, or else mixed with a "citrate solution," and before the end of 1917 the methods of transfusion and the classification of donors were standardized in every casualty clearing station, with the consequent saving of many lives. During 1917 also much more attention had been paid to the treatment of shock, and in every casualty clearing station a special hut or tent was provided where arrangements were made for warming such patients, for administering rectal injections, or for transfusing blood.

In addition to all these changes, the careful splinting of fractures had been greatly developed. It was at the end of 1915 that the "Thomas' knee splint" began to be used for a few cases of fracture of the femur, but it was not until the Battle of the Somme in 1916 that it came into general use during heavy fighting. In anticipation of this battle it had been supplied in large numbers to all the casualty clearing stations, and during the progress of the battles its use was taught to the field ambulances also by the consulting surgeons of the armies engaged. Its value was immensely increased by the invention in 1915 in the First Army of the "Stretcher Suspension Bar," which enabled the limb to be comfortably slung during the transport of the patient. And in 1917, before the British attacks began in April, the use of the Thomas' splint and the suspension bar had been demonstrated by the consulting surgeons of all armies throughout the field ambulances, so that as the year progressed this method of splinting was carried as far forward as the regimental aid posts. Greatly improved splints of various kinds for the upper extremity had also been

provided in large numbers, and it had become the custom to put up all fractured limbs in suitable splints before the patient was removed from the battle area, with the result that the condition of patients on arrival at the casualty clearing station was very greatly improved. In the large majority of these cases there was no such shock as had always been the case when smashed limbs had been only imperfectly immobilized during transport by road.

As the natural result of all these improvements, the beginning of the last year of the war found the casualty clearing stations in every way better able to look after the wounded, and this was not only because there were now so many experienced surgeons but because there had been an advance in surgical methods and equipment. The experience gained by the commanding officers also was of the greatest value in the invention of ingenious methods of utilizing huts and tents to the greatest advantage. The methods of pitching the latter quickly, and so as to make convenient wards and dressing rooms, had undergone great improvements ; the supplies from ordnance stores and from the Red Cross depots gave an infinitely greater amount of gowns, towels, gloves and so on, for the surgeons and nurses, while the selection of suitable N.C.O.'s and orderlies added to the experience of many battles had resulted in more rapid methods of recording particulars and of dealing with blankets, stretchers and motor ambulances than in former periods. Finally, but most important, it was now recognized that for heavy fighting it was essential that orderlies should be supplemented by from 50 to 100 stretcher bearers, and it had also been reiterated in many reports that stretcher carrying was very heavy work for which men of low category were of little value.

It must also be noted that the whole motor ambulance transport had become most efficient. The transport was really the pivot on which the whole surgery of the front turned, for unless the wounded could be rapidly evacuated from the field ambulances the casualty clearing station surgeons could not get to work. The original custom of collecting large numbers of wounded in field ambulances and then sending them down *en masse* had long been given up, and every single man urgently requiring treatment at a casualty clearing station was brought direct to the latter in a special car from the advanced dressing station of the field ambulance. The cars were now often heated by warm air from the exhaust of the engine, and plenty of hot-water bottles and blankets were to be obtained.

The year 1917 had again been a costly one, for the total wounded amounted to 495,000. Yet in spite of the great numbers there was no doubt that the wounded men had been very much better cared for and treated than in the previous years of the war.

Before considering the closing stages of the war it will be convenient to allude briefly to the pathological laboratories of the front. In each of the five armies laboratories for pathological work were instituted, and many of them were attached to the casualty clearing station groups. As a result of this, not only was it easy to obtain the pathological reports required for the treatment of individual cases in the casualty clearing stations, but in quiet times very valuable research work was carried on, and much of what was learnt of gas gangrene and of shock was the direct consequence of the activities of these units.

Occasional meetings of medical officers at the front began to be held at the end of 1915, but it was only at the end of 1916 that they became of much importance. They took place at various casualty clearing stations, and were encouraged and organized by the Directors of Medical Services and the consulting surgeons. Not only did they help to spread in each army a knowledge of recent developments in any one casualty clearing station, but they also provided an opportunity for discussing the work done in other armies, or in the general hospitals. In this way the knowledge of improved methods or technique, or of new bacteriological and other advances, was rapidly spread to the great advantage of the whole service.

At the end of 1917 also arrangements were made for the interchange of surgeons between the casualty clearing stations and the general hospitals. Until this was done it was often difficult for the surgeons at the front to learn by experience what happened to the patients evacuated by them to the lines of communication, and on the other hand a visit to the front for several weeks showed the surgeon who had only worked at a general hospital the difficulties due to delay in rescuing wounded men, and to the rush of wounded into the casualty clearing stations when heavy fighting was in progress. Such experience was very shortly to prove valuable.

Mention must here be made of the creation in the First Army of a medical school attached to one of its casualty clearing stations, where a course lasting fourteen days was instituted. Its object was to instruct men who had not yet had experience of work in casualty clearing stations in the

recent developments of military surgery, and to show what might be done at aid posts or field ambulances. These courses were especially helpful to young medical officers who had only recently arrived from England, and had perhaps only lately become qualified to practice. They learnt especially the methods of resuscitating badly injured men and also the application and uses of new varieties of the splints used at the front. There were also lectures on military law, map-reading, and the common diseases of the horse. The success of this school resulted in the creation in the spring of 1918 of a school for the whole expeditionary force, and it was evident that, had the war continued, this would have been of great service.

During the winter of 1917-18 the operating theatres of all the lines of communication hospitals were, on the recommendation of the advising consulting surgeon, fitted with extra operating tables and instruments in anticipation of an enemy attack and of difficulties arising in the operation work at the front. In September 1916 instructions had been issued by the D.G.M.S. to make arrangements for the greater mobility of sections of the casualty clearing stations, and orders were given for schedules to be prepared showing what material could be carried on nine 3-ton lorries. Arrangements were also made to echelon the casualty clearing stations, and some of the most advanced of these were withdrawn in anticipation of a German attack. In spite of these precautions, however, the enemy advance of 21st March rapidly endangered the casualty clearing stations of the Fifth and Third Armies, and although they were able to do very valuable work for several days, they had then to be evacuated, and most of their equipment was sacrificed although no patients were left behind. As they withdrew they gradually reverted to a large extent to their original rôle of clearing the field ambulances, and entraining centres were formed at places like Villers-Bretonneux and behind Albert and Amiens, where dressings were applied and limbs were splinted, the patients being evacuated both by road and rail to the general hospitals in the rear for operative work. Further north, in the areas of the First and Second Armies, where the attack did not develop so quickly, the casualty clearing stations were withdrawn successfully and re-established farther back. As a result of this, they were able to deal with the wounded with the same efficiency as in 1917, although the work had to be done in tents for the most part. Very efficient operating theatres were also developed by the

ingenious pitching of several marquees together, and from this time onward the proportion of tents to huts became very greatly increased. As an example of work in this period, it may be noted that the First Army had 12,865 wounded between 9th April and 21st April, and that 23·5 per cent. of these were passed through the operating theatres of the casualty clearing stations before being evacuated. By the month of May the line had become again stabilized, and the front-line surgery had resumed its former routine. But, in view of probable British advances in the near future, more mobile operation and X-ray huts were designed, and a mobile operating theatre with its surgical equipment, which had been designed in the First Army, was now supplied to other armies also. It was constructed so as to be mounted on an Air Force trailer and could be hauled by any lorry.

On 27th May the German armies attacked in the Chemin des Dames region, where six British divisions were attached to the French forces, and No. 37 Casualty Clearing Station was captured together with about 200 wounded men. The staff remained, and were permitted to continue in charge of their patients for the next two or three weeks. Six weeks later three casualty clearing stations were again in the French area, one at Sezanne, south of the Marne, one at Epernay, and one at Senlis. Their presence in these regions was called for because two British divisions were co-operating with the French near Villers Cotterets, and two others were between the Marne and the city of Rheims. The sites of these casualty clearing stations were settled by the French authorities, but they were at far too great a distance from the fighting line, with the result that it took so many hours to transport the wounded that an ambulance car could only make about two double journeys in twenty-four hours. Many of our wounded were, therefore, treated in the French hospitals, and several hundred more were taken to an American general hospital at Dijon. The casualty clearing stations also had not been able to take nearly all their equipment with them because of difficulties in train transport, and the advanced depots of medical stores encountered similar difficulty. The consequence was a shortage of essential splints, for the number of wounded admitted to British casualty clearing stations was over 5,000.

The opening of the great British offensive on 8th August found the casualty clearing stations both fully staffed and well equipped, for all the loss of material and equipment due to the German attack of March had long since been made good,

and several units were already packed up and waiting to move forward with the advance. The proximity of the Amiens front to the general hospitals stationed at Abbeville and Rouen also permitted of many patients being evacuated to these areas who would ordinarily have been retained in the casualty clearing stations. The new arrangements making for increased mobility worked very well, and as early as 9th August two casualty clearing stations were pushed up and opened for work in the Asylum at Dury, and on the 10th two more in tents at Vecquemont. Between 8th and 12th August about 19,000 wounded were treated in the casualty clearing stations, and about 10 to 15 per cent. of these passed through the operating theatres. Nearly all the wounds were due to rifles and machine-guns fired at longer ranges than had previously been used, and consequently the proportion of slight wounds was very much higher than in the case of shell injuries. It must also be noted that, as all the general hospitals on the lines of communication had been supplied with extra operation tables and instruments, they were able to do much more surgery than ever before. The result of this combined work at the casualty clearing stations and the general hospitals was most satisfactory, and inquiries made on 13th August showed that of a total of 10,000 wounded admitted to the Tréport, Abbeville and Rouen areas the mortality had been only one-half per cent., the amputation rate one-half per cent., and the incidence of gas gangrene one-quarter per cent.

August saw a rapid extension of the attack northwards, so that the casualty clearing stations of the Third Army became very busy. This was followed at the end of the month by an extension of activities to the First Army, with the result that in four weeks from 8th August over 103,000 wounded men had been treated in the casualty clearing stations. Both in August and September the casualty clearing stations were well able to keep touch with the advance, and early in the latter month they were across the Somme in the south. All huts except those for operation and X-rays had been left behind, and tents alone were in use. Only a very little time was now required to make ready for work on a new site. For example, on 18th September a casualty clearing station was moved up to Doignt near Peronne to be ready for heavy fighting. It arrived at 6 p.m., took in and treated more than 500 patients before noon next day, and within the week it again moved a few miles to another site. Similar instances occurred in other parts of the line.

As a result of the British attacks of 27th, 28th and 29th September the Hindenburg line was broken, and the army advanced in October to the other side of the devastated area where towns and villages with good buildings were occupied. Consequently, as at Caudry, the casualty clearing stations were housed in large factories and other industrial buildings, while farther north, at Douai and elsewhere, existing hospital buildings were taken over. In the wetter and colder weather these were a great advantage to the wounded men, of whom there was a total for the month of September of over 105,000.

The Fourth, Third and First Armies had severe fighting and sustained many casualties in the first fortnight of October, and on 14th October the Second Army in the Ypres region continued the offensive it had begun on 28th September, and three tented casualty clearing stations were established at Brielen, just behind Ypres, in readiness for work. Fortunately the wounded here were few as compared with previous attacks farther south, and amounted altogether to 1,166 in three days. Of these no fewer than 457 were passed through the operating theatres. The great majority were wounded by bullets, for the Germans had withdrawn most of their guns, and it was on this day that the last shell was fired into Ypres, almost exactly four years since the bombardment commenced.

From this date till the end of the war difficulties increased daily, for the British armies were now faced with railways so destroyed as to be for the time irreparable, and with roads blown up at numerous places. The consequence was that there was so great a demand for lorries for the supplies of food and ammunition that the casualty clearing stations often could not be moved for want of transport, and as time went on the difficulties increased as the advancing troops left the railways farther and farther behind them, and as the lorries broke down from excessive work on very bad roads. Here and there, as at Carnières, Daddizele and Roubaix, sections of casualty clearing stations were pushed forward to do the more urgent surgery, pending the supply of transport for the rest of the unit, but for the most part the wounded had to be brought back fifteen or twenty miles before a casualty clearing station was reached.

In addition to these difficulties large numbers of sick or wounded civilians, including many women and children, had to be taken in and cared for, whilst the occurrence of a severe epidemic of influenza and pneumonia caused dangerous illness in many thousands of soldiers who had to be evacuated

to the general hospitals. The staffs of the casualty clearing stations and field ambulances also did not escape the prevailing epidemic, so that the work of all the front-line units became most difficult. Fortunately the numbers of wounded fell materially in the latter half of October, and at the same time shell wounds still caused only a minority of the casualties, so that the proportion of badly wounded men remained low. The total number of wounded passing through the casualty clearing stations in the month of October reached over 88,000, but in spite of all the difficulties wounds did well, and the reports from the lines of communication showed that there was still a low rate of mortality and of wound complications.

The total number of wounded treated in the casualty clearing stations during the advance commencing on 8th August was nearly 312,000, and for the whole year 598,000.

Method of Working a Casualty Clearing Station.

It may be well to describe the way in which a casualty clearing station was working at the end of the war, so that a comparison may be made with its manner of working in May 1915. In 1918 the casualty clearing stations were grouped and housed in a series of lashed tents. Each took in one hundred and fifty wounded in action before switching off to another casualty clearing station. There was a large party of bearers, made up of men of low category or, possibly, convalescent patients, and the wounded man was lifted from the ambulance and taken into a long reception room made of five or six tents. Here he was seen by the receiving officer who separated the cases, the medical being sent to medical wards.

After the particulars had been taken by the clerks, the wounded man was carried to the dressing tent, where his wound, if slight, was dressed, and he was then taken to the evacuation ward, which was near the road. If more seriously wounded he was passed on to the pre-operation ward, where his clothes were cut off, and he was cleansed, warmed and fed. If on arrival the condition of a patient was found too serious for operation, he was taken to the resuscitation ward, where a medical officer, a sister and orderlies attended to his revivification; he was rested, warmed, infused or transfused as might be necessary. By the end of the war the practice of transfusion had attained a high pitch of excellence, and the number of transfusions in a single unit very often reached a dozen in a day.

Next to the resuscitation and pre-operation wards was the

X-ray department, through which every man requiring X-ray examination passed before he was taken to the theatre ready for operation. In the operating theatre a great change from the early days had taken place. There were one or two theatres accommodating twelve tables arranged in pairs, each pair being divided from the other so as to give a little privacy. Two tables were provided for each team in order to prevent waste of time.

After operation the man was carried out, and if his injury was comparatively slight he was placed in the evacuation ward which, as already stated, was somewhere near the road. If too ill to be evacuated, he was taken into the retention ward, which was situated in as quiet a place as possible at the back of the casualty clearing station; there he was attended to by the nurses and medical officers.

It will therefore be seen that there was a definite route marked out for every man arriving in the casualty clearing station, and so well were arrangements carried out, that if a visitor entered when a convoy had ceased arriving he might stand in the centre and find it hard to believe that the place was working at fever heat day and night. Towards the end of the war the practice had arisen of separating the walking wounded from those who were more seriously injured. The idea was to make the working of the casualty clearing station, where seriously wounded were received, quieter and easier, for the walking wounded had a great tendency to stroll about the place to seek out friends and create a considerable amount of noise in talking to them.

Two plans were adopted in fixing the site of these walking wounded casualty clearing stations. One plan was to push a casualty clearing station as far forward as possible and evacuate the wounded on temporary ambulance trains; the other was to carry the walking wounded back from the active area by a light railway.

The following is a description of a walking wounded casualty clearing station which was established about 7 kilometres south of Arras, during the fighting in September 1918, when the Canadians broke the Quéant-Drocourt line. The wounded arrived by lorry from the front or by an improvized train from Quéant. The lorries drew up in front of three huge reception rooms, each made of eight lashed tents, for it was necessary to get the walking wounded under cover and within some bounds. In each of these three reception rooms was a coffee-bar kept by the Y.M.C.A. Across each room, about

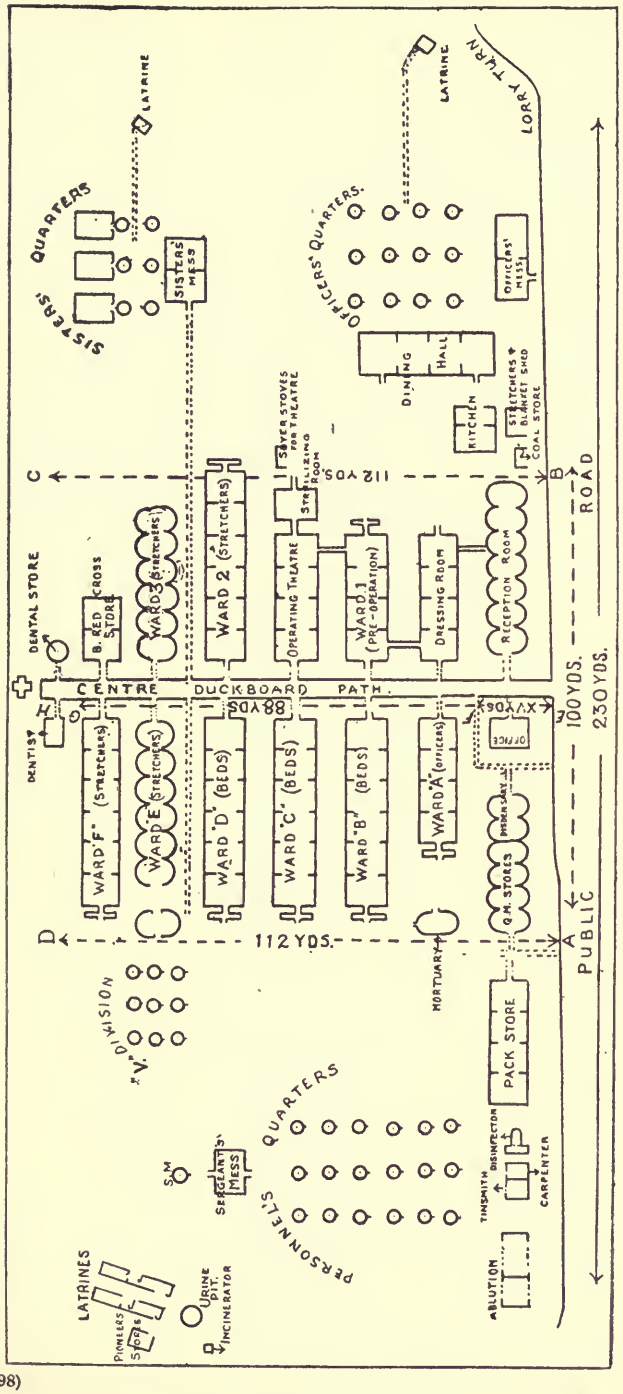

Fig. 1.—Sketch plan of casualty clearing station for seriously wounded.

two-thirds down, were tables at which the clerks sat. The men passed through spaces left between the tables and the particulars were recorded. When the man emerged from the big tent a duck-walk led to the dressing tent. This was a long room made of eight marquees; down its centre was a series of tables with surgical material. When the man entered the dressing tent an orderly bared his chest, cleaned it, applied iodine and passed him on to another orderly, who gave him antitetanic

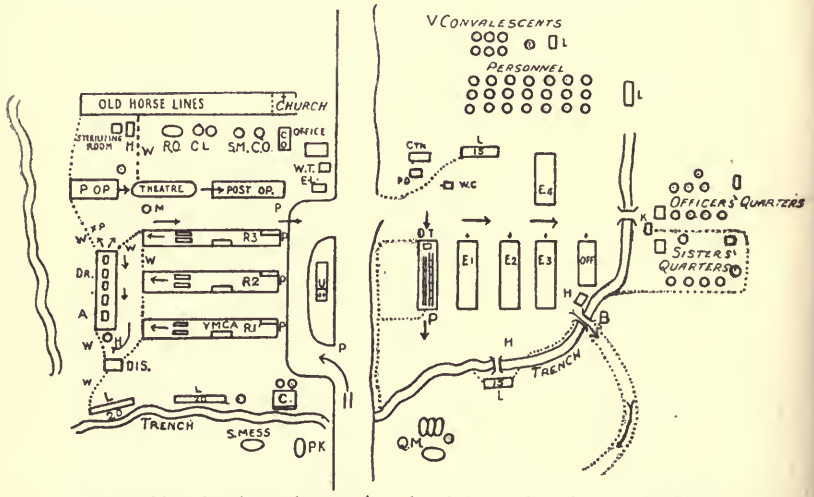

Fig. 2.—Sketch plan of casualty clearing station for walking wounded. A., A.T.S. team; B., Bridge leading out of camp; C., Cook-house; C.O., Commanding Officer's office; DIS., Dispensary; DR., Dressing tent; D.T., Dining tent; E., Evacuation wards; H., Hot-water boiler; E.L., Electric light engine; K., Officers' mess kitchen; L., Latrines; M., Matron's office; O., Office; OFF., Officers' ward; P., Policeman; PK., Pack store; P.OP., Pre-operation ward; E.O., Evacuation officer; POST OP., Cases for evacuation; QM., Steward's stores, etc.; R., Reception; R.O., Recording office; SM., Sergeant-Major; TH., Theatre; U., Urinal; W.C., Water-cart; W.T., Water tanks; CL., Clerks.

serum. The man then took one of the vacant places on the benches, where he was attended to by the sister and orderlies working under a medical officer. He passed out of the long tent and was conducted into another series of tents where there were stretchers on which he could lie down, or, if he wished, he could go to a dining tent. When an ambulance train arrived the men were marshalled by non-commissioned officers and marched down to it. A pre-operation ward, a theatre and a post-operation ward were provided, for about 4 per cent. of wounded required operation and about 10 per cent. of them became "lying cases" for one reason or another.

The Regional Incidence of Gunshot Wounds.

A table showing the incidence of wounds in trench warfare in 1915 is given on p. 28, but it must be kept in mind that in the fortnight during which these figures were collected the troops were in the trenches and there were no raids of any importance on the enemy lines. It will be seen that out of a total of 3,285 the wounds were situated as follows, steel helmets being not yet in general use :—

Head, face and neck	761
Shoulder and back	360
Chest	167
Abdomen	100
Lower extremities, including buttocks	997
Upper extremities	614
Multiple	286

It should also be noted that only a little more than a quarter of the total wounds, namely, 897, were attributed to bullets, and there is no doubt that in attacks on enemy positions and in the open warfare of the latest stages of the war the proportion of wounds by bullets from rifles and machine-guns was very much higher than in the earlier stages.

What was probably of greater importance was the relative incidence of " dangerous " wounds, for a wound of the " back " or the " buttock " might mean a wound of the lung or the abdomen, and a wound of the " thigh " or the " arm " might or might not be complicated by fracture of a bone or the opening of a large joint. What really interested the surgeon and was of vital importance was the percentage of wounded men demanding some special treatment, for on this depended the whole of the arrangements for surgical treatment in the casualty clearing stations. In the first place it was necessary to provide a sufficient number of splints for patients with fractured bones, and it was also advisable to be able to arrange for the treatment of wounds of the different viscera and to set apart certain beds for patients with wounds of the abdomen, head and other severe injuries. After some experience it became possible to forecast with sufficient accuracy the expected number of serious or dangerous wounds in any big attack, and a very simple rule enabled all arrangements to be made. This was called by Sir Anthony Bowlby the " two per cent. rule," for out of every hundred cases certain wounds might each be expected to occur in 2 per cent. of the patients. The following table shows the distribution per cent. of serious wounds and the number of splints required for fractures.

TABLE I.

Wound.	Percentage.	No. of splints required.	
		Lower Extremity.	Upper Extremity.
Skull	2	—	—
Lungs	2	—	—
Abdomen (penetrating)	2	—	—
Fractured femur	2	6	—
Wounded knee-joint	2		—
Fractured leg or foot	2		—
Fractured humerus	2	—	6
Fracture about elbow-joint ..	2	—	
Fractured forearm	2	—	

It will be seen that these injuries collectively amount to 18 per cent. of the total, and the remaining 82 per cent. would include a large number of slighter injuries and flesh wounds, together with a few serious wounds of the face and neck which did not require special apparatus or treatment. Additional splints for flesh wounds of the extremities could be supplied. On the whole, and taking large numbers of wounded, the "2 per cent. rule" provided a margin for all the wounds enumerated, except in the case of the lungs which slightly exceeded two per cent. Thus, in the attacks by the Fifth Army in 1917, out of 60,000 consecutive wounded men there were 2·5 per cent. lung cases, 1·58 per cent. abdominal cases, and 1·68 per cent. cases of fractured femur.

The figures in Table II were obtained by the D.M.S. of the Fifth Army in 1917, and show the total number of wounded in ten consecutive attacks in the Ypres salient, and the percentage of certain wounds in 60,724 patients. The whole table forms a most useful guide in making arrangements for surgical work in casualty clearing stations.

It must be noted that in 1917 all troops were provided with steel helmets and that these greatly diminished the number of severe injuries of the skull. In connection with this question the following extract from a report by the advising consulting surgeon, dated 3rd March 1916, is of some historical interest. The occasion was an attack on "The Bluff" by the 3rd Division of the Second Army, and this was met by a very heavy fire in which shrapnel predominated, a large percentage of all the wounds being caused by shrapnel bullets.

"The attack of to-day is the first in which our men have practically all worn the new steel helmets, and I, therefore, spent some time in investigating the effects of this form of

TABLE II.

Incidence of Wounds in Ten Attacks during the Third Battle of Ypres by the Fifth Army.

Period.	Total Wounded.	Special Injuries Admitted.			
		Skull.	Penetrating Chest.	Penetrating Abdomen	Fracture Thigh.
6 a.m. 31/7/17 to 6 a.m. 3/8/17 ..	19,987	306	404	568	264
6 a.m. 16/8/17 to 6 a.m. 18/8/17 ..	9,935	168	305	244	169
6 a.m. 20/9/17 to 6 a.m. 22/9/17 ..	6,219	88	187	109	103
6 a.m. 26/9/17 to 6 a.m. 28/9/17 ..	4,565	58	117	82	74
6 a.m. 4/10/17 to 6 a.m. 6/10/17 ..	3,620	62	107	59	53
6 a.m. 9/10/17 to 6 a.m. 11/10/17 ..	4,674	47	92	52	47
6 a.m. 12/10/17 to 6 a.m. 14/10/17 ..	4,598	43	90	46	44
12 noon 22/10/17 to 12 noon 24/10/17 ..	2,506	26	36	20	28
12 noon 26/10/17 to 12 noon 28/10/17 ..	3,440	33	38	35	39
12 noon 30/10/17 to 12 noon 31/10/17 ..	1,180	14	18	16	18
Totals ..	60,724	845	1,394	1,231	839

	Skull.	Penetrating Chest.	Penetrating Abdomen	Fracture Thigh.
Percentage of each special injury to total admissions	1·39	2·29	2·02	1·38
Lowest percentages in any one action	0·93	1·10	1·0	0·95
Highest percentages in any one action	1·70	3·05	2·84	1·70

protection. Officers and men alike spoke with the greatest enthusiasm of the helmets, which, they said, had protected them especially from the fire of trench-mortars and shrapnel. My own examination fully confirmed this, for nearly forty out of about the first 350 helmets examined showed evidence of having been hit. In some the metal had been only excoriated. In others it had been definitely bulged in. In a few it had been perforated. One helmet showed three large bulges, each as big as the bowl of a small teaspoon, yet the man's head was unwounded. In others, the helmets had been torn open by large shell fragments without the skull being injured."

There can be no doubt that if troops do not wear these helmets the incidence of dangerous head wounds will largely exceed 2 per cent.

Operations and Mortality in Casualty Clearing Stations.

The following tables illustrate some interesting points. Table III shows the mortality at a casualty clearing station, and it will be noted that the mortality is much higher in winter than in summer, due probably to the effects of cold.

TABLE III.

Mortality at a Casualty Clearing Station.

	Admitted.	Died.	Death-rate per cent.
A. *Statistics of Wounded admitted over a consecutive period of* 36 *months,* 1*st May* 1915—30*th April* 1918*	11,155	467	4·2
B. *Statistics during four periods of activity :—*			
i. May, 1915 (Festubert)	1,913	24	1·3
ii. September, 1915 (Battle of Loos) ..	1,242	34	2·7
iii. March, 1918 (Merville No. 2 Site; mainly shell wounds from back area shelling)	380	38	10·0
iv. April, 1918 (Haverskerque Site; time of retreat; wounded left behind)	745	16	2·1
C. *Statistics during three periods of Summer Trench Warfare :—*			
i. June—August, 1915	1,093	42	4·0
ii. June—August, 1916	1,793	63	3·5
iii. June—August, 1917†	701	18	2·5
D. *Statistics during three periods of Winter Trench Warfare :—*			
i. December—February, 1915–16 ..	571	50	8·8
ii. December—February, 1916–17 ..	358	30	8·3
iii. December—February, 1917†–18 ..	176	7	4·0

* Supplied by Colonel C. H. S. Frankau.

† An advanced operating centre was taking the more seriously wounded.

In quiet periods in a casualty clearing station, medical officers put 50 per cent. of wounded on the operating table, and, to avoid dangerous operations at the base, had to operate on 25 per cent. As one surgical team does twelve operations in twelve hours, two surgical teams were required for every hundred wounded. Table IV shows the composition of ten surgical teams required to work a casualty clearing station taking in 500 wounded in twenty-four hours.

TABLE IV.

	Medical Officers.
For theatre	20
Reception and dressing	4
Chest and medical	1
Resuscitation	2
Care of unfit for transport	2
Entraining officer	1
X-ray	2
Total	32

Table V shows what operating work was actually accomplished, and it will be noted that only occasionally, even over a prolonged period made up of active and quiet times, did the casualty clearing station reach the 50 per cent. standard. In attacks, where the wounded were suddenly thrown on the casualty clearing stations in a limited time, the task was even greater and the percentage operated on lower. The high percentage reached in the Nieppe Forest attack was due to the small number of wounded received.

TABLE V.

Number of Wounded Operated on in various Battles.

	Period during which wounded were received.	Wounded.	Percentage of Operations.
Vimy Ridge	2 days	3,600	16
Messines	2 days	18,000	16
Hill 70 (Loos, August 1917)	4 days	4,158	29
Third Battle of Ypres	3 days	19,000	16
Battle of Estaires (1918)	10 days	12,865	23
Defence of Nieppe Forest	1 day	800	36
Canal du Nord	6 days	14,169	17

In the battle of Arras, April 1917, the figures are not complete, but the percentage of wounded operated upon, according to H. M. W. Gray, was 24. Similarly, in the

battle of Amiens in August 1918, when the first advance took place, the percentage of operations is shown as 15 during a period of four days, although the number of wounded to which the percentage refers has not been given.

Table VI shows what was accomplished in the battle of Estaires, 9th April 1918. It will be noted how the percentage varied from day to day and how the casualty clearing station always strove after the 50 per cent. standard.

TABLE VI.

Date.	No. of Wounded (excluding Gassed Cases).	Percentage of Wounded Operated on.
April 9th, 1918..	1,870	9
,, 10th	2,615	14
,, 11th	1,659	17
,, 12th	1,808	16
,, 13th	869	25
,, 14th	645	36
,, 15th	496	43
,, 16th	252	53
,, 17th	451	43
,, 18th	1,137	29
,, 19th	395	51
,, 20th	222	50
,, 21st	446	46
Total	12,865	23·5

Methods of Wound Treatment at the Front.

Iodine and Cyanide Gauze.—In the earlier stages of the war, wounds when first seen by a surgeon were commonly painted with a solution of iodine and dressed with cyanide gauze, and this method was adopted both at field ambulances and casualty clearing stations in pursuance of a policy adopted before the war. It was, however, found that the combination of iodine and cyanide was liable to cause severe blistering of the skin around the wound and, as far as preventing sepsis was concerned, it appeared that the treatment had no definite advantages. In consequence of these results, the combination of these agents was abandoned after a time.

Early use of Strong Antiseptics. Carbolic Acid.—One result of the septic conditions of the wounds in patients who had been sent to England straight from the front in 1914, was that many surgeons at home concluded that the early use of strong

antiseptics should be adopted and, owing to this advocacy, a thorough trial was made in November 1914 of carbolic acid, either pure or in strong solutions, but no good results were obtained and its use was abandoned.

Borsal Powder and Cresol Paste.—In February 1915, Sir Watson Cheyne advocated the use of an antiseptic powder and an antiseptic paste. The first consisted of equal parts of powdered salicylic and boric acid and was named " Borsal." The second was of three varieties :—

(1)	Ac. salicylic powder	20 parts.
	Ac. boric powder	20 parts.
	Tragacanth gum	2 parts.
(2)	Ac. salicylic	6 parts by weight.
	Ac. carbolic	1 part by weight.
	Glycerine	8 parts by weight.
(3)	Lanolin	78 per cent.
	Cresol	20 per cent.
	Wax	2 per cent.

It was hoped that the paste, by giving off its antiseptic slowly, would thus act on the infecting agent continuously. A supply of these pastes and powders was, therefore, sent to France on 4th April 1915, and they were tested both by a surgeon, who had been instructed in their use in England by Sir Watson Cheyne, and also by other surgeons selected for the purpose in France. The following document of instructions was supplied by Sir Watson Cheyne, and was distributed together with the antiseptic agents :—

" Directions for the use of Borsal Powder and Cresol Paste."

" In the case of a wound at the Front the first thing is, of course, to stay the bleeding as much as possible, and then to powder the whole surface thickly with the borsal powder. The cresol tube is then introduced into the wound and small quantities of the contents are squeezed into it in various directions, endeavouring as far as possible to leave small portions of the paste scattered over the whole area of the wound, not more than 1 in. apart. Some of the paste should also be smeared over the skin around the wound, and after a final dusting with the borsal powder the emergency dressing is applied. This can all be done quite quickly, and then the patient can wait till such time as the wound can be more thoroughly attended to.

When the patient arrives at the advanced dressing station, the treatment depends on circumstances.

(1) If a large number of wounded have to be attended to, patients who have been treated in the above manner can wait, unless a good many hours have elapsed since the injury. In that case the orderlies should inject a little more paste into the wounds and powder them and apply a fresh antiseptic dressing while the patient waits his turn. In the case of wounds which have not been treated, the orderlies should apply the powder and paste at once.

(2) If it is a large or complicated wound, *e.g.*, a compound fracture, it will be well in the first instance to clean and disinfect the skin, preferably with 1 in 20 carbolic lotion, then wash out the wound with peroxide of hydrogen and 1 in 20 carbolic lotion, remove pieces of clothing or accessible pieces of shell, clip away any badly soiled tags of tissue and arrest the bleeding. The

wound being dried and held open it can now be powdered with borsal and some cresol paste left in various parts of the wound. If it is widely open it may be well to put a few interrupted sutures in to bring the edges somewhat together and prevent the escape of the antiseptic, and finally apply antiseptic dressings.

(3) If it is not a large wound, if the clot seems solid and if it has been well powdered and plenty of paste introduced into it in the first instance, it is quite possible that sepsis may not occur and if that seems likely all that need be done would be to squeeze a little fresh paste and dust some borsal powder over the surface and the skin around and apply a fresh antiseptic dressing.

These wounds will probably not require further dressing till they arrive at the base hospital.

Subsequent Treatment at the Base.—Should the wound be free from sepsis or inflammation on arrival at the base hospital it should not be opened up or syringed or otherwise interfered with. Some fresh paste, diluted if necessary, may be applied over the surface and the skin, and a fresh antiseptic dressing put on.

If, on the other hand, there are signs of sepsis, the wound must be opened up and drained and otherwise treated according to the experience of the surgeon."

These instructions were carried out in various parts of the front, and the patients so treated were, in some cases, retained for observation, and in others were sent at once to the general hospitals. Although the treatment was at first carried out with much enthusiasm, there was a general consensus of opinion that it was positively harmful, and the following report, dated 17th May 1915, on cases treated with cresol paste is typical of the opinions of practically all the surgeons who were asked to record their experiences :—

"At the present time there are in this hospital 28 cases which have been treated with cresol paste. Many more have been passed through recently but no record has been kept of their number or condition.

So far as my observations go, the results obtained have not been satisfactory.

Some of the cases have obviously been anæsthetized, the damaged edges of the skin wounds excised, the openings enlarged, good drainage provided and the paste introduced. These have been on the whole satisfactory, but the results, if as good, are no better than in similar cases simply treated by incision and free drainage.

In cases which have been treated simply by external cleansing, injection of paste, and the application of protective dressing, the use of the paste appears to have a harmful effect. In the cases of the latter group the wounds are commonly found plugged with a mass of coagulated blood and paste. When the plug is removed a profuse discharge escapes, the tissues are greatly swollen and gas is not uncommonly present.

(1) The paste with the blood forms a dense putty-like mass which plugs the wound openings, dams up the secretions and by interfering with drainage pre-disposes to diffuse septic infiltration.

(2) The paste and blood coagulum adhere very closely to the tissues. It has been found to be very difficult to clean up wounds treated with the paste.

(3) There is often excoriation of skin edges and blistering of surrounding skin surface due apparently to the action of the paste.

(4) It does not appear that any useful effect has resulted from the use of the paste."

It only remains to add that the opinions of surgeons, both at the front and at the base, were unanimous, and the further use of both powder and paste was stopped.

Hypertonic Saline Solution.—The treatment of wounds by the use of a strong solution (60 grains to the ounce) of common salt was advocated by Sir Almroth Wright in 1914 and 1915. It was employed chiefly in the base hospitals and was never widely adopted in the front-line units. Its employment is described more fully on p. 252, but its use was accompanied by much secondary hæmorrhage and it was gradually abandoned in favour of better methods, and was practically not employed in the casualty clearing stations after 1915.

Various Antiseptics.—All kinds of solutions were employed to wash the wounds, and various powders, such as iodoform or boric acid, were used, but none of these agents prevented the wounds from suppurating or obviated the need of free drainage. Various aniline dyes in oily solutions were also employed but with no better results.

Carrel's Method of Wound Treatment is described in the sections dealing with wounds in the general hospitals.

Early Excision of Damaged Tissues.—The treatment of wounds by free excision at the casualty clearing stations was generally adopted as an alternative to the use of free incisions for drainage, and after the year 1915 it became a common practice during quiet periods. It could not, however, be employed at that time during a battle because of the small size of the clearing stations and the scarcity of their surgical personnel, and it was not until the first battle of the Somme in 1916 that it began to be adopted at the front on a large scale. From that time on it was the regular practice, and was proved to be the most efficacious means for the prevention and arrest of gas gangrene. The earlier this treatment was carried out and the more thorough the removal of all torn muscle and foreign bodies, the more satisfactory were the results, and during the heavy fighting of the year 1917 the large majority of all the severe wounds were treated in the casualty clearing stations by this method. Only when the numbers of wounded became too great were such patients sent to the base before operation. It was found to be most important not to excise any skin, although free incisions to get at the deeper parts were commonly required. If skin were removed healing was often much delayed, and experience showed that skin could always be cleansed if sufficient care was exercised.

Suture of Wounds.—The wounds treated by suture in the

early days of the war did badly, and as a result the closure of wounds fell into complete disuse for the next year or two. In 1917 suture was again tried, but then only under good aseptic conditions and after the excision of damaged tissues and the removal of all foreign bodies, and it was soon found that under these circumstances very good results could be obtained. The consequence was that during the year suture became more and more widely adopted. At the end of 1917 an investigation was carried out in order to ascertain what rules should be adopted, and a report by Captain Forbes Fraser was circulated in March 1918.

Experience in all areas showed that the great majority of wounds could be safely sutured if the patients were treated within about twenty-four hours, and if no virulent hæmolytic streptococci were present ; the latter were found in about 10 to 15 per cent. of all wounds. It was also found by many surgeons that if a wound was extensive, and if the oozing of blood could not be completely controlled, it was better to leave the wound unsutured for from one to three days, and the same method was adopted if the surgeon was in any doubt whether the wound was already too widely infected for a complete disinfection to be ensured. In yet other cases where, after the excision of a large wound, the patient had to be at once evacuated by train, it was again found better not to suture at once because the movement and the shaking were liable to result in fresh bleeding and distension of the wound with retained blood.

In all such conditions, therefore, the wound was lightly filled with sterilized gauze and bandaged, and it was found that it could then be safely left for a period of from one to three days. After this interval the patient was anæsthetized, the gauze removed as gently as possible and the sutures inserted and tied. Experience showed that it was better to do no more than this, and that washing of the wound or wiping it with gauze was harmful. This suturing of a wound at the time of the first change of dressing was called " delayed primary suture," and it was found useful to supply to the casualty clearing stations labels with the letters " D.P.S." so that the operating surgeon at the front could by their use indicate to the surgeon at the general hospital which cases were, in his opinion, ready for suture. Once the wound was closed it was very important for success that the injured limb or other part should be immobilized as much as possible by the application of splints and bandages, and also that the patient himself should be kept recumbent for some days.

Various antiseptics for sutured wounds were employed, such as the mercuric salts, carbolic acid, solution of hypochlorous acid, flavine, and a paste containing bismuth, iodoform and paraffin, commonly known as "B.I.P." Each of these had its advocates, and the lotions were no doubt useful in cleansing the skin around a wound as well as the tissues exposed by operation. The general opinion ultimately was that completeness and thoroughness of the surgical operation were sufficient to ensure healing, and that no antiseptic was essential. At the same time many surgeons considered that the slightly sticky surfaces resulting from the use of weak solutions of flavine (1–2,000) were an aid to suture, and others continued to use "B.I.P." and to believe that they got better results with it than without it. On the other hand, there is no doubt that large masses of "B.I.P.," left in a wound not only became practically foreign bodies, but also involved a risk to the patient and caused poisoning of a dangerous nature.

As experience of suture increased it was found safe to operate upon and suture many wounds which had been left untreated for as long as forty-eight hours or more, and during the heavy fighting of 1918 an increasing percentage of all wounds were successfully closed either by "primary" or "delayed primary" suture. The following extracts from reports by general and stationary hospitals will serve as examples.

At No. 22 General Hospital, out of a series of 5,539 wounded who had arrived in August and September 1918, after an interval of forty-eight hours since being wounded, 741 cases were treated by primary suture, and 192 by delayed primary suture. Of the primary sutures 88 per cent. were successful in spite of the fact that either bones or joints were involved in no less than 184 patients. Of the delayed primary sutures, 81 per cent. were successful.

The consulting surgeon at Dannes Camiers base reported that between 8th August and 13th August 1918, out of 2,008 cases 683 wounds were sutured. Of these 625 were closed by primary suture and 50 by delayed primary suture with a total success of 91 per cent. In cases operated upon within twenty-four hours after being sutured, success was obtained in 95 per cent., but in cases between twenty-four and forty-eight hours only 85 per cent. were successful.

At No. 9 General Hospital, observations were made in April 1918 on 1,274 patients who did not arrive until after an interval of fifty-eight hours on the average after being

wounded, the shortest period being twenty-four hours and the longest one hundred and fifty hours. Of these cases 420 were operated upon, and in 44 the wound was closed by primary suture with complete success. A further 67 were treated by delayed primary suture with 91 per cent. of successes. It was the experience of the surgical staff that every wound that had not progressed to abscess and new tissue formation should be treated by operation and excision of damaged parts. If sepsis was more advanced it was better to make incisions in skin or fascia and to drain rather than to excise.

The foregoing reports clearly show that the early suture of wounds resulted in the rapid healing of the great majority thus treated, and it must be pointed out that those wounds which were not treated by operation and suture included the majority of the clean perforating bullet wounds with small entrance and exit apertures, as well as a large number of superficial scratches and abrasions which did not penetrate the whole thickness of the skin. Neither of these classes necessitated excision as a routine measure, and it was especially the lacerated wounds caused by shells and bombs which called for this treatment, for not only were the muscles more extensively torn and crushed, but the missile was more often retained and portions of clothing and mud or of broken wood or stone were often carried into the tissues and resulted in a very gross infection.

Experience in the casualty clearing stations during quiet periods had resulted during the last eighteen months of hostilities in the practice of operating on about 70 per cent. of all wounded men as early as they could be brought in from the field ambulances, and the great majority of these wounds were sutured as a rule. It may therefore be concluded that excision and suture were regarded at the end of the war as the ideal method of treatment for most gunshot wounds.

The advantages of the successful suture of wounds were very great and far reaching. As far as the patient was concerned, he was freed from the anxiety and pain of frequent dressings and from the discomfort inseparable from an open wound. He was also spared the danger to life of septic absorption and its attendant pyrexia and illness. In many cases he was convalescent in a few days instead of being invalided for many weeks or months. Experience and investigation at the general hospitals in 1918 showed very clearly the danger of leaving wounds unclosed, for it was found that, while only about 10 per cent. of all open wounds

were infected with streptococci on arrival from the front, within a week over 90 per cent. had become infected. A committee for the investigation of how this infection occurred was sitting at the time of the armistice, and it had been already found that many of the nurses and orderlies were "carriers" of streptococci in their throats. No doubt other sources of infection would have been discovered, but the risk of streptococcal infection was a strong argument in favour of the early closing of wounds.

From the point of view of the army the benefits of early suture were also very great, for the surgeons, nurses and orderlies were relieved of the frequent dressing of wounds, and much saving resulted in gauze, wool, bandages, and other dressings. The hospital beds also were not occupied so long, for not only did patients quickly convalesce, but the much more rapid union of fractures enabled patients to leave their beds much earlier and with much less stiffened and crippled limbs than after long suppuration. Finally, the army itself benefited by the rapid return to duty of large numbers of wounded soldiers, some of whom, except for the aseptic healing of their wounds, would never have been fit to return at all.

CHAPTER XII.

WOUND TREATMENT IN GENERAL HOSPITALS IN FRANCE.

THE outbreak of war in August 1914, found surgical opinion in a fairly settled state regarding the main principles governing the treatment of wounds. These principles were based upon experience gained in the practice of the surgery of civilian life and upon that of the South African War, substantially corroborated by succeeding campaigns, notably the Russo-Japanese.

'Surgeons, therefore, entered upon the work of the war with small anticipation that views cherished and implicitly relied upon were destined to be rudely shaken, or that experience gained during half a century of continuous progress was shortly to be tested by a repetition of nearly every step which had progressively led up to the position of surgical security which it was assumed had been reached.'

This disconcerting discovery is to be referred to many reasons, amongst which may be pointed out first of all the want of familiarity with the treatment of grossly infected wounds. Few of the surgeons employed in the early part of the war had any conception of the course taken by infected wounds in the pre-Listerian period. The great majority had been educated under a system which excluded the possibility of such experience being acquired; and in their later practice, observance of the rules upon which they had been taught to rely had not failed to ensure to them the success they expected in the treatment of wounds. When one considers the enormous extension of the field of surgical enterprise which had resulted from this well-placed confidence in the power to avoid and control the complications liable to follow a wound, it is easy to understand that little misgiving existed as to the power of the surgeon to deal promptly and successfully with the injuries of warfare.

This confidence, moreover, seemed justified by all recent experience of the simple course taken by bullet wounds of all but the most severe types, and it was upon wounds inflicted by bullets of small calibre that modern military surgery had been mainly practised. In the abundance of observations of injuries to all parts of the body by bullets, and the marvellous success which had attended their treatment, it had practically

been forgotten that even in recent campaigns it had been observed that "shell wounds, with the exception of clean leaden shrapnel bullet tracks, always suppurated."

Two other main factors played an important part in the difficulties which had to be met, one the delay in transport of the wounded men, inseparable from the conditions of warfare; and the second, to which, perhaps, too great importance has been attributed, the nature of the soil with which the majority of the wounds were "fouled."

It may be fairly stated that at the commencement of the war most surgeons inclined to the belief that a prompt application of a solution of iodine in spirit would suffice for the primary disinfection of a wound of moderate size. Such a belief had been strengthened by the common use of a similar solution for disinfection of the skin prior to the performance of surgical operations and as a precaution against the suppuration of stitch punctures. Hence a small capsule of a 2 per cent. solution of iodine was added in 1915 to the first field dressing, and the great majority of the wounds were treated at the field ambulances and casualty clearing stations with repeated applications of the same medium.

In the casualty clearing stations in the early period hydrogen peroxide was freely used, and considerable confidence existed as to its power to control the multiplication of anaërobic organisms. During the first few months the officers serving in the forward units had sufficient confidence in the reliability of disinfection of this nature to close up by suture the wounds of lesser magnitude, and also those of amputations and incisions for the removal of foreign bodies. Other antiseptic solutions were used by individual surgeons to a lesser extent, such as mercuric chloride 1–1,000, carbolic acid 5 per cent., weak solutions of formaline, the composite solution recommended by Sir G. C. Cheatle, 5 per cent. carbolic acid in water mixed with 0·2 per cent. of mercuric chloride in spirit, lysol and applications of pure carbolic acid, or carbolic acid and crystals of camphor.

Wounds treated by these different media reached the general hospitals in very varied states. A certain number of the slighter injuries arrived in excellent condition, particularly the superficial flesh wounds with wide openings, and type wounds caused by bullets. Wounds that had been closed by suture, those which had been insufficiently opened up, as a result of the early ignorance of the extensive internal injury which might exist when the apertures of entry and exit of the missile

were small or moderate in size, and most wounds of an "explosive" character were usually found heavily infected and in a terrible condition. A very large proportion were in the acute stages of anaërobic infection, hence gas gangrene, either of the localized or massive type, was frequently witnessed, and many limbs and lives were lost; acute tetanus was common.

The general procedure adopted at the hospitals on the lines of communication at this period consisted in opening up the wounds freely, in providing counter openings to ensure drainage and arrest wider extension of the process of infection, and in the application of hot fomentations most commonly of boracic acid or weak carbolic acid solutions. The use of the continuous or interrupted bath was also common, the most satisfactory solution being iodine water (3 drachms of the tincture of iodine to the pint). Under this treatment many of the wounds improved rapidly in condition; sloughs separated, the surface became covered with healthy bright red granulations and suppuration was free. In such cases the general condition of the patients was remarkably good; they ate and slept well, were cheerful, the tongues were clean, and rises of pulse or body temperature moderate.

At this stage the appearance of the large wounds, especially those complicated by the presence of a fracture, was very striking. The superficial surface had usually diminished considerably in extent, but the local reaction to the infection had resulted in a considerable area of protective induration of the tissues bounding the wound, giving rise to a rigid eversion of its margins, while the cavity was surrounded by a resistant wall covered by granulations which bled freely when interfered with. The resemblance to the so-called crateriform ulcer of malignant disease was very marked.

Under these conditions further progress was slow, the most important local element was the ensurance of satisfactory "rest" to the injured part, and the whole gamut of astringent and antiseptic applications from red lotion to iodoform was passed under review. During warm and sunny weather one of the most successful methods consisted in keeping the patients in the open air, and exposing the wound for definite periods to the sun's rays. Unfortunately the season suitable for this method of treatment rapidly passed by.

To turn from these, the more successful cases, a large number of men perished from acute toxæmia, progressive suppuration and septicæmia or, more rarely, metastatic

pyæmia ; while others who had commenced a successful battle with infection gave way later, and eventually died from general infection of the system. During the whole of this period a host of efforts was made to try to arrest the spread of infection by the local application of antiseptics, although the conviction was steadily strengthening that the only effective means at the disposal of the surgeon were mechanical in nature and consisted in the judicious use of the knife and scissors.

Such was the condition of affairs when Sir Almroth Wright commenced the observations which stirred up surgeons generally to an activity of thought on the subject which had perhaps been previously wanting, and led them back to the period in which Hunter and Lister had so vividly impressed the vital nature of the process of wound healing and the innate power of the organism to protect and repair itself.

A memorandum under the names of Colonels F. F. Burghard, Sir W. B. Leishman, Sir Berkeley Moynihan and Sir Almroth Wright was circulated, in which certain rules were laid down starting from the acknowledged fact that in any deep or perforating wound effective sterilization of the tissues by antiseptic media is impossible. Cleansing and drainage of the wound cavity being the primary measure, it was laid down that sutures were not to be employed, nor the wound wrapped up air tight ; and that prophylactic injections of antitoxic sera, or certain vaccines, were possible ancillary measures for control of infection.

So far the memorandum introduced no novel suggestions, but from this point Sir Almroth Wright took up a line of his own, founded on experience gained in the employment of the so-called " Wright's solution," for the treatment of chronic suppurative wounds and sinuses. He expressed the opinion that the primary object of opening up wounds and infected tissues and the provision of drainage was to provide issue for pus and infected discharges ; but he stated that the mere provision of an outlet was not enough, nor was it enough to see the outlet so disposed as to allow of gravity carrying off accumulated discharges ; to these measures must be superadded a system of lymph lavage of the tissues.

Wright considered that the object sought was not attained until such lymph as might have become poisonous to leucocytes and impotent towards bacteria had been replaced by a lymph favourable to phagocytic activity and inimical to microbes, and until this last was being " drawn " into the wound and establishing conditions favourable to healing. When anything

less than this had been achieved by the use of the knife, and particularly if in despite of incisions the infection process had advanced, drainage operations had failed in their object, the failure being attributable to sealing up of the fenestræ in the tissues and stanching of the lymph outflow.

The remedy suggested was to apply a hypertonic solution of salt to promote the outflow of lymph. The solution recommended consisted of a 5 per cent. solution of common salt, combined with 0·5 per cent. of citrate of soda to render the lymph incoagulable. Where citrate of soda was not obtainable, a simple 5 per cent. solution of salt would serve. In dealing with dry and infiltrated wound surfaces, the use of stronger solutions of salt (up to 10 per cent.) was stated to resolve the induration and clean up the wound surface more quickly than weaker solutions.

The method of application recommended was, in the case of deep wounds, to pour in the hypertonic solution, and then plug lightly with gauze. Superficial wounds were dealt with by laying gauze thoroughly soaked in the solution upon the surface. An application of vaseline was counselled to prevent irritation of the surrounding skin and stinging on freshly cut skin surfaces, the limb being wrapped in waterproof material to protect the bedding from the very copious discharge.

Frequent washing out and dressing of the wound was laid down as a dominant factor in the treatment of infection ; and, further, immersion in a bath or continuous irrigation with some aseptic or mildly antiseptic fluid was emphasized as the ideal method of treatment as long as the wound remained heavily infected. The " drawing agent " was considered to have done its work as soon as spreading invasion of the tissues by infection was checked, or the dry and indurated wound surface had clothed itself with bright coral-red granulations. The hypertonic solution might then be replaced by a simple dressing, or when the infection had been brought under control free exposure to the air might be tried.

It was at the same time suggested that in imperfectly drained wounds the use of vaccines, while producing nothing of the nature of dramatic results, might yet produce a certain improvement in local conditions together with a certain protection against septicæmia. Thus it might be possible to employ conservative measures in a larger number of cases, to hold on longer to these methods, and to carry them more often to a successful issue. Vaccine therapy was, therefore, considered advisable as a part of the routine treatment of

suppurating wounds, it being clearly understood to be an ancillary method and always secondary to efficient surgical measures.

The memorandum attracted general attention, and the hypertonic or physiological method of wound treatment obtained a prominent place amongst the procedures employed.

It is unnecessary to follow the development of the physiological, or, as Sir Almroth Wright preferred to call it later, the phylacagogic method. But Wright, in common with the surgeons, recognized the efficacy of proper primary mechanical cleansing of the wound and advocated its necessity, although throughout he remained a determined opponent of the use of chemical antiseptic media. He further devised ingenious methods of applying his own solutions, of which perhaps the most interesting were concerned in the procedure of wound irrigation. He pointed out that the drip method in common use resulted in the early formation of a local channel by which the fluid passed, leaving the remainder of the cavity untouched. To obviate this disadvantage he made use of strips of woven bandage arranged in the cavity of the wound. These he regarded as conduit pipes with porous walls, capable of conveying fluid upward by capillary attraction, downward by gravity, and first up and then down when arranged as syphons. The device was widely used, but required close attention if it was to work successfully, for in this respect more supervision was required than in the application of the Carrel-Dakin procedure. The "irrigation flange," built up of wool and covered by a water-tight layer of strips of bandage permeated by formaline gelatine (gelatine 20 gr., water 100 c.c., formalin 40 per cent. 10 c.c.), was also a very useful addition to the procedure of irrigation in preventing diffusion of the fluid into the bed of the patient.

At this period an attempt was made to obtain more exact information as to the actual results following the primary application of chemical antiseptic media, and a limited trial was undertaken with this object. It was decided that 100 wounds should be treated, half by the application of pure carbolic acid, and half by the 2 per cent. iodine solution; that the treatment should be under the observation of Sir Anthony Bowlby at the front; that the patients should be provided with special tallies, and be sent down to No. 13 General Hospital in Boulogne for further observation. This plan was carried out, the cases coming under the care of Fitzmaurice Kelly, while Fleming carried out the necessary

bacteriological investigations. The work at the base was done under the observation of Colonels Sir Almroth Wright, Sir G. H. Makins, and F. F. Burghard.

The results obtained were shortly as follows :—

Of the 50 cases treated with pure carbolic acid, only 27, as the result of accidents of transport, reached the hospital where observations were being made.

Period elapsing between the reception of the wound and the application of the permanent dressing :—

In 8 cases .. .. 12 hours.
In 16 cases .. .. 24 hours.
In 2 cases .. .. 48 hours.
In 1 case .. .. 3 days.

Period elapsing before arrival at the base :—

In 13 cases .. .. .. 2 days after injury.
In 12 cases .. .. .. 3 days after injury.
In 1 case .. .. 4 days after injury.
In 1 case .. .. 10 days after injury.

Nature of the Wounds :—Five superficial wounds, eight deep penetrating wounds, seven wounds of the hand, two wounds of one finger, three compound fractures of the thigh, two compound fractures of the arm.

Condition of Wounds on Admission :—Thirteen were classified as " clean " but infected (in two of these, fractures of the femur and humerus respectively, large drainage tubes had been inserted), eight were classified as " foul," two were suppurating freely, and four had definite gaseous cellulitis.

Of the 50 patients, one, who did not reach the base, developed gaseous cellulitis the day after the application of the pure carbolic acid, was unfit to travel and died at the casualty clearing station.

In two of the cases no material for culture could be obtained as they had already healed. In the remaining 25, organisms were present, *Bacillus perfringens* in all but five.

In 16 the organisms were mixed.
In 2 *B. perfringens* and streptococcus.
In 2 *B. perfringens* only.
In 2 staphylococcus only.
In 1 streptococcus and coliform bacilli.
In 1 *B. perfringens* and staphylococcus.
In 1 streptococcus and staphylococcus.

The whole 50 cases treated with 2 per cent. iodine solution reached the base.

Period elapsing between the reception of the wound and application of the permanent dressing :—

In 13 less than 1 hour.
In 12 within 2 hours.
In 7 within 10 hours.
In 4 within 12 hours.
In 6 within 20 hours.
In 8 within 24 hours.

Period elapsing before arrival at the base :—

In 20, 2 days.
In 9, 2½ days.
In 19, 3 days.
In 2, 4 days.

Nature of the Wounds :—16 superficial wounds or simple perforations, 23 deeply penetrating wounds, two slight wounds of hand or finger, five wounds of scalp or face, one fractured humerus, one fractured radius, two wounds of toe.

Ten wounds were " actually clean," that is, no organisms could be cultivated from them. All these were of a trivial or slight character. No cases arrived with gaseous cellulitis.

In six cases the healed condition of the wound allowed no material for culture to be obtained. In 14 cases no organisms were culturable. Of the remaining 30 cases :—

In 17, *B. perfringens* with other organisms.
In 2, *B. perfringens* alone.
In 3, undetermined bacilli and micrococci.
In 1, staphylococcus alone.
In 4, streptococcus alone.
In 2, diplococcus and staphylococcus.
In 1, diplococcus and *B. subtilis*.

A comparison of the two series appears manifestly in favour of iodine as an antiseptic medium, but several sources of fallacy prevent the observations from carrying much weight.

(1) The 27 cases included in the carbolic series were certainly of a more generally serious nature than those of the iodine series.
(2) Examination of the tables shows that the iodine treatment (probably from comparative ease of transport at the particular time) was more promptly applied.
(3) The patients treated with iodine arrived more quickly at their destination in the base hospital.

Bearing these three points in mind it may still be broadly stated that in no case did the iodine treatment act harmfully, while the number of clean cases was considerable.

With regard to the carbolic series, in several instances the acid, by favouring the formation of an extensive coagulum, led to the development of a firm scab which by closing the wound aperture resulted in harmful retention of discharge and more extensive infection of the tissues. The observations in any case showed that completely successful results were not to be obtained by the use of pure carbolic acid, and that the employment of this medium without free drainage had dangers of its own.

Consideration of the two series combined showed conclusively that under the conditions which attended the treatment of the wounds, namely, the gross nature of the contamination of the tissues, and the interval of time which elapsed between reception of the injury and the attempt to render a wound cavity aseptic, little success was to be hoped for by treatment of serious wounds by chemical antiseptics. In practically no instance did a wound of any extent arrive at the base free from infection. The organisms present, with but a few exceptions, comprised the anaërobes amongst their number, and *Streptococcus pyogenes* was present in nearly all. On the other hand, the degree and extent of the infection were obviously dependent on the thoroughness with which provision had been made

for effective drainage of the wound. Where this had been efficient the wounds, while not aseptic, were nevertheless in good condition, and offered little difficulty in further treatment. It is of interest to note that the officers at so early a stage as the field ambulance already in their reports referred to the growing tendency to rely on free drainage.

The experience gained at the base hospitals may be shortly summed up as follows :—

(1) All cases except those of the simplest type of bullet wounds were infected at the time of reception into the base hospital.

(2) The mere fact of infection, which was recognized as inevitable under the conditions to which the patients were necessarily subjected, proved of minor importance provided that the wounds had been efficiently drained.

(3) The cases which did badly were those in which either from the topography of the wound, or as a result of obstruction of the external opening, free discharge had been interfered with. Thus in practically every case in which the wound was closed by sutures, extension of the area of infected tissue resulted, and the first step in treatment at the base hospital consisted in removal of the sutures and free opening up of the wound. This was specially the case in wounds of the face, in scalp wounds and fractures of the skull, whether or not a primary operation had been performed.

Again, the number of amputations which healed primarily after suture, even with the provision of drainage which would be considered in civil practice more than ample, certainly did not exceed 5 per cent. In many cases free sloughing of the flaps took place, and in the vast majority extensive suppuration. In practically every amputation which had been closed it was necessary as a first step at the base to remove the sutures. The effect of early transport was particularly bad in these cases. Even when incisions had been made through normal tissue for the removal of bullets, the wounds if sutured suppurated eventually; while on several occasions bacteriological investigation at the base showed retained bullets to be sterile, even when the wound of entry was infected.

Bad results were usually seen in cases in which it was considered necessary to introduce plugs, or where the application of strong antiseptics to a wound leading to a large internal cavity led to the formation of a firm crust obstructing the external aperture. On the other hand, the introduction of a

large drainage tube, even without the provision of a counter opening, appeared to ensure a "healthy wound," in spite of the occurrence of infection, and such cases usually did well.

It appears to be possible to draw but one conclusion from these observations, namely, the importance of the mechanical factor in the treatment of the wound. Thorough mechanical cleansing of the surfaces, the provision of effectual drainage by the introduction of large tubes, the avoidance of the use of sutures or any form of plug calculated to interfere with the free flow of lymph or later pus, are the primary measures on which chief reliance can be placed.

The application of chemical antiseptics is only to be regarded as one part of the procedure directed towards the destruction or inhibition of free organisms within the wound cavity, and in the tissues which immediately bound it, and as preventing the external dressings from forming a suitable nidus for abundant bacteriological growth in direct contact with the wound.

It is obvious that at this stage two or three fundamental principles of wound treatment had received abundant confirmation—thus, that infected wounds should not be closed; that free drainage should be afforded for the wound discharges; that a want of proper rest favoured the extension of the process of infection, and that abortion of a commencing infection could not be produced by any chemical antiseptic media then employed, if the infective organisms had already penetrated into the tissues.

The more important feature in view of future developments lay in the increasing value attributed to early mechanical treatment of the wound in the direction of the removal of fouled or disintegrated tissue by the knife or scissors.

The practical experience gained by surgeons on the spot, however, failed to produce a corresponding influence on those who were treating the patients in England. The arrival at the base hospitals at home of patients who from necessities of accommodation had been evacuated from France before the process of infection had become localized, and of the very much larger number in whom the disturbance inseparable from transport started further extension of an infection which had quieted down, gave rise to a feeling of disquietude which resulted in much criticism and a number of suggestions as to lines of antiseptic treatment which should be adopted.

Of these, the methods directed to an immediate primary sterilization of the wound by the application of chemical media scarcely need special mention; but a record of one method

founded on the principle suggested by Lister cannot be omitted, namely that of providing a reservoir of an antiseptic medium to be placed in the wound as a preliminary measure pending the time when a thorough inspection and cleansing operation could be undertaken. The methods suggested by Lister himself had never obtained a satisfactory trial, and bearing in mind his own dictum, " If for example a pair of forceps is handed to the operator with the intervals between the teeth occupied by dry septic pus, and a portion of this dirt becomes detached and left in the wound, the evil cannot be corrected by any antiseptic wash that is now at our disposal or that the world is ever likely to see," one cannot suppose that after the date 1891, on which this statement was made, he could himself have any great confidence in the efficiency of the " reservoir " method.

Two media were employed for establishing an antiseptic reservoir, namely, a paste, the active principle of which was cresol, and a powder consisting of a mixture of boric acid and salicylic acid. As noted in the previous chapter, both were the outcome of investigations made by Sir W. Watson Cheyne and a committee, appointed by the Director-General of the Medical Department of the Navy in December 1914, to enquire into the best method of treating wounds sustained in action, especially during the early period after their infliction.

The chief object of the research was to study the best methods of dealing with wounds in the interval between their infliction and the arrival of the patient at a dressing station or elsewhere, where the wound could be properly attended to, an interval not infrequently of several hours and sometimes even of days. It was suggested that if there could be introduced into the wound at the time of, or soon after, its infliction some antiseptic substance which was capable of diffusing through the blood clot and tissues and inhibiting the growth of bacteria till such time as thorough disinfection could be carried out, a great deal might be gained as regards the prevention or diminution of septic and other pathogenic infections.

Simple fluid antiseptic media were considered unsuitable, as they would be washed away by the serum poured into the wound and would, at most, only exercise a transitory effect. A powder alone would be inconvenient and possibly inefficient from the difficulty of its introduction into recesses and its tendency to be washed away by serous discharge. Hence it was decided to make a sticky paste of some kind the basis

of the antiseptic medium, and a combination with some greasy ointment was considered to be the most satisfactory substance. Experiments were made with a number of antiseptics in order to determine their power of inhibiting bacterial growth or killing the organisms. It is noteworthy that the more striking results were obtained in laboratory cultivations on agar plates, in which the disturbing influence of constant circulation of the blood through the tissues bounding a wound surface was eliminated, as also the influence of tissue products in destroying the active power of the antiseptic chosen ; also, that the *Streptococcus pyogenes* was not amongst the organisms selected for investigation.

The paste eventually selected consisted of pure hydrous lanoline 5 parts, beeswax 1 part, to which 20 per cent. of cresol was added. The cresol employed was a combination of redistilled ortho-meta and para-cresol, prepared by Mr. Martindale.

The powder consisted of salicylic acid and boric acid in equal parts.

It was recommended that the powder should be dusted thickly over the wound from a pepper pot, and that its action should be reinforced by the introduction of cresol paste squeezed from small " paint tubes " containing half an ounce of the mass. It was directed that a tube should be used for one patient only, and then thrown away. Detailed printed instructions were issued together with the preparations. In April 1915, a supply was sent over to the army in France, and was distributed amongst some of the forward units, and shortly afterwards a further supply was brought from England by Captain Addinsell who was attached to a definite unit in order to make a personal trial.

When cases treated by the method first began to arrive at the general hospitals on the lines of communications, they gave rise to considerable perplexity. In slight and in open gaping wounds no special criticism was aroused ; but in severe deep wounds, especially those in which moderate-sized apertures of entry and exit were combined with extensive internal injury, and those complicated by fracture or the retention of clothing and missiles, the condition was most unsatisfactory. In the latter class of injury the wound aperture was often blocked by a mass consisting of a mixture of powder, paste and blood clot, or a dark evil-smelling discharge was exuding. The limbs were swollen and acute progressive infection of the tissues was present. When opened up a surface resembling breaking down or necrotic liver substance was exposed, and cleansing

of the wound was a matter of great difficulty as a consequence of the firm adherence of the powder and paste to the irregular wound surface.

Reports obtained from fifteen general or stationary hospitals were uniformly unfavourable to the use of the method, and it may be fairly stated that the condition of the wounds generally was no better than if they had been sent down untreated, while in many instances the paste had actually caused ill-effects by blocking up the apertures of entry and exit. In the latter class a considerable layer of the tissues in immediate contact with the antiseptic paste was devitalized, and behind this saprophytic bacilli were multiplying freely. It was evident that the most serious consequences observed in this series of cases depended upon the neglect of any proper provision for drainage, and perhaps the too abundant application of the paste and powder. In both these respects, however, the surgeons had strictly followed the instructions issued with the media.

It has already been stated that in the slighter injuries no special consequence followed the use of the paste and powder, hence the best results were seen in the case of wounds of the trunk, and in this connection a small special series of cases must be mentioned. Twenty-four cases, of which half were treated by the routine methods in use at the time, and half by the application of borsal powder and cresol paste, were brought down by Captain Addinsell for investigation. The whole number were treated under abnormal and unusually favourable conditions, since they remained in the front units for periods of from twelve to nineteen days. Examination of the two series revealed no obvious difference between them, and certainly no superiority in those cases in which the cresol paste and borsal powder had been applied. No cases of fracture of the thigh, no serious fracture of the leg, no wounded knee joint, and no fracture of the skull were included in either series.

All of the twenty-four patients presented clean granulating wounds, and in none of the men was any serious sign of systemic absorption present in spite of the existence of suppuration. In eight of the cases treated with cresol paste bacteriological examination was made by Captain Parry Morgan. In all, organisms either streptococci or staphylococci were present and cultivable, and in one instance *Bacillus perfringens*.

In fairness to both methods, Captain Addinsell's own description of the procedure he adopted should be quoted.

" The skin around the wound was washed with hydrogen peroxide and warm water. The wound was cleansed with hydrogen peroxide and all clots, clothing or missiles removed. Where necessary the wound was freely opened up, thoroughly cleansed with 5 per cent. carbolic lotion, lightly dusted with borsal, and every pocket or interstice treated with cresol paste. Free drainage was always ensured, and a dressing of gauze applied." It will be observed that in this series of cases, all the precautions which experience had shown to be necessary in the treatment of cases at the front were observed, and the instructions issued with the media were not followed. The result consequently demonstrated clearly that provided the routine method then in use at the forward units was adhered to, the particular form of antiseptic application adopted was not of great consequence. One single property of the cresol stood out, its analgesic power, which recommended itself to the patients and was not to be underrated. General experience on the other hand had demonstrated clearly that the " reservoir " system in the absence of proper mechanical treatment was powerless to inhibit or prevent spreading infection of the tissues and its consequences, and in deep or widely spread injuries introduced dangers of its own. From this period the method was entirely given up.

In the period which immediately followed the failure of the reservoir method, certain developments occurred of which the most important were the use of the so-called " salt pack," and the introduction of the hypochlorites in the form of " eusol " and " eupad."

The salt pack may be first dealt with. At an early date Lt.-Colonel C. B. Lawson advocated the placing of tablets of chloride and citrate of sodium within the folds of gauze used for filling the cavity of a wound. Colonel H. M. W. Gray took up this method with great enthusiasm and developed it upon more extensive lines. It obtained many warm adherents, especially in the Rouen area, and later, for a short time in a few of the casualty clearing stations.

The grounds upon which the treatment was introduced may be shortly detailed in Gray's own words. " For routine and general use under such conditions as exist on the British front and lines of communication in France, it is requisite that some dressing should be available which is effective in preventing severe sepsis, easy to carry, simple in application, economical of material and time, and so continuous in action that little attention is necessary during transport. Hypertonic saline

dressing, especially in the form now known as 'the tablet and gauze pack' fulfils these desiderata better than any other yet applied. As Lawson has said, 'many wounds treated in this way arrive in such excellent condition, that during a rush the men can be transferred directly to England without more interference than adjusting the superficial dressings. The patients' temperatures are normal and the wounds are free from surrounding inflammation.' The slow dissolution of the tablets in the folds of gauze, which sometimes occupies many days, provides a continuous supply of hypertonic solution until they are completely dissolved."

With regard to the indications for the choice of the pack method, Gray laid down that "although the clinical characters of the wounded part often give quite reliable indications of the important bacteriological contents, yet a report from the laboratory on the kind of organisms present may be of the greatest service. For example, the streptococcus thrives in lymph, but finds in the phagocyte a deadly enemy. Therefore, when it is found that streptococci are making headway in a wound, or are found in pure culture in a joint, isotonic solutions, as laid down by Wright, should be used for the treatment of the wound or washing out the joint. In ordinary deep wounds, however, and especially in the early stages, when multiple infection is likely to be present, hypertonic applications are the best."

The method recommended for dealing with the wound prior to insertion of the pack is as follows:—

Free incision or excision of the superficial parts of the wound, including, especially, the deep fascia, is practically essential to success in order to make it possible to cleanse and drain thoroughly and to insert the "tablet and gauze pack" properly.

Exposed aponeurotic structures are certain to slough, hence they should be cut away. At the beginning of the war there existed a great antipathy in many quarters to making fresh incisions in the presence of acute and even chronic sepsis, because it was thought that such incisions, by laying bare fresh tissue, entailed a greater risk from the spread of infection than the simple insertion of a large drainage tube through a smaller opening. When suitable saline treatment was used it was found that there was no such increase in danger, but, indeed, the reverse. Counter-openings at the most dependent parts of the wound cavity are of great importance in certain cases.

A lacerated deep wound should be thoroughly opened up and every pocket of it examined and enlarged, if necessary. Meticulous care should be exercised in removing foreign bodies and blood clot by forceps, fingers or swabs, and all necrotic or badly lacerated muscle or fibrous tissue should be clipped away. Irrigation is rarely necessary or desirable.

If the dead space due to the wound can be obliterated by suitable bandaging, if effusion is likely to be small in amount, and if the wounded part has been rendered aseptic, there is really no necessity for drainage. In wounds involving the cranial, pleural, or articular cavities, the drain should be introduced "down to but not into," the cavity. When wounds become healthy, if there be no necrotic tissue in the depth, it is desirable to remove drains altogether, provided the surfaces of the wound are forced into contact, but it is probably safer practice to shorten them gradually. Rigid drains should give place to soft drains made of jaconette, batiste, torn glove, or absorbent bandage, as soon as the discharge ceases comparatively to be profuse.

As regards the method of application of the tablet and gauze packs, after the wound has been cleansed by operation the recesses are to be sought out with the finger and filled firmly with gauze wrung out of 5 to 10 per cent. salt solution, numerous tablets of salt being enclosed in the folds of the gauze. Blood clot which may form during the process of packing should be wiped away. The gauze should be packed in concertina-wise, one tablet being placed between every third or fourth fold. A fairly large fenestrated rubber tube is placed so as to reach to the deepest part of the main cavity which is then filled with gauze and tablets. The dressing is made flush with the skin, and the tube projects slightly from its midst. The surrounding skin is painted with a solution of iodine, or other antiseptic application. Two or three layers of gauze are then used to cover the wound and the surrounding skin. A suitable amount of absorbent cotton wool is added, and a bandage applied smoothly and firmly. Should pus collect in any isolated part of the wound, it is not necessary always to remove the whole of the pack, and thus cause the patient unnecessary pain and jeopardize the healing of the rest of the wound. Irrigation and drainage of the affected part may be instituted. The rest of the pack will probably become loose in a few days. If it is suspected that any part of the wound will give trouble in this way, a drain down to that part should always be inserted. Efficient fixation of the wounded part must be secured by proper bandaging or splints.

A few remarks will suffice to dismiss the salt pack and tablet system. Originating from Wright's hypertonic treatment, it in no way fulfilled the objects aimed at by his method except in so far as the presence of the hygroscopic salt and foreign body in the cavity of the wound induced a free outflow of serum. The salt tablets themselves formed an irritant, and where the tablets came into near contact with the tissues a superficial slough was produced. As the supporters of the method themselves allowed, the presence of so strong a solution of chloride of sodium in direct contact with the tissues restricted or abolished the process of phagocytosis. Lastly, the avoidance of induration in the wall of the wound, one of the conditions which Wright aimed at in his early work, was in no sense attained. The method was also objectionable from the point of view of the amenities of the ward from the fact that putrefactive organisms which developed freely in the cavity and the pack itself gave rise to a most objectionable smell.

Nevertheless, for many reasons the method grew rapidly in favour. It could be said that in the main it fulfilled the claims that were made on its behalf, provided it was properly carried out. It afforded the enormous advantage of obviating frequent dressings, thereby avoiding re-infection and recurring pain on the part of the patient, while at the same time great economy in dressing materials was attained. The wounded part was given rest and the development of granulations in the cavity was neither hindered nor disturbed. Meanwhile, except for rises of temperature, which experience proved were not to be regarded as dangerous in the absence of signs of local extension of the infection, the general condition of the patients was remarkably good. The treatment was widely adopted in the Rouen area, and during the early months of 1916 a considerable number of cases arrived at the hospitals on the lines of communication where the method had been adopted as a primary treatment.

There were two reasons why the first experiences gained were in great measure disappointing. In the first place, the surgeons at the front had not all appreciated the fact that the pack treatment was a source of very great danger if applied to any wounds in which the cavity could not be actually and accurately filled, for example, in deep and complicated lesions, especially those in which a compound fracture was present. In the second place, the cases on arrival at general hospitals were distributed to surgeons who had not fully

grasped the theory that the pack did not need to be disturbed simply because it stank and the patient's temperature was elevated. As a consequence of these two factors, some patients arrived in a serious state as a result of extending infection, while others were subjected to the unnecessary pain of removal of an adherent pack and the risk of a fresh extension of the infection.

At a later period both these objections to the method disappeared. It was not uncommon to leave the pack in position for a period of as long as ten days when after removal of the gauze the wound was found in such a condition that only a few days of careful treatment sufficed to permit of its being closed by secondary suture. If the pack was retained too long the walls of the cavity tended to stiffen unduly, and repeated packing led to delay in closing the cavity. At a still later date, in place of using solution of iodine to the skin, Gray sprinkled the exposed surface of the pack freely with chloramine T., in the hope of reducing the degree of objectionable smell. In spite of such success as may have been attained, the method fell into disuse as the principles which eventually governed the primary treatment of gunshot wounds developed, and it cannot be regarded as likely to be resorted to in the future.

With regard to the claims made for this method of wound treatment it may be well to make two further remarks. First with regard to the objection to its unpleasant odour in the wards, Captains J. E. H. Roberts and R. S. S. Statham, reported as follows :—" After a few days the outer dressings may acquire a very offensive odour. This is due to decomposition in the dressings themselves, and if they are removed the wound is found to be perfectly sweet. The outer dressings are more offensive than the inner. At one time we changed the outer dressings when they began to smell, leaving the inner untouched. The objection to this is that it is difficult to change the outer dressings without disturbing the deep pack. We used various substances, such as sanitas powder, potassium permanganate and eupad powder, thickly dusted on the dressing immediately beneath the cutermost layer of gauze. All these diminish the odour. With Dakin's chloramine T. powder which we are now using, all odour is practically abolished." Secondly, with regard to the reported general condition of the patient and the state of the wound, it must not be forgotten that in the earliest stages of the war, when the conditions of the wounds were seen

at their worst, the good general condition of a large number of patients and the healthiness of the granulating surfaces gave rise to surprise. Thus Makins reported in October 1914, that "the vast majority of the wounds do well, the bullet wounds of the soft parts taking the same uneventful course already familiar. In the more serious injuries due to shrapnel or fragments of shells a few days' rest usually suffices to re-invigorate the patients; there is little evidence of constitutional infection, either in the general appearance, the temperature, or the pulse-rate, and the men eat, drink, and sleep well."

Hull modified Gray's method by filling the wound cavity with a number of small sacs made up from strips of woven bandage containing powdered salt. It was claimed that the higher the concentration of salt, the greater would be its power of attracting water and albuminous substances. The sacs were retained in position for six days. It cannot be said that any advantage could be claimed for this method beyond the economy involved in the substitution of common salt for the more expensive tabloids, while on the other hand the great advantage of the loose gauze in accurately filling crevices in the wall of the wound was lost.

In 1915, an extensive use of hypochlorous acid and the hypochlorites was introduced. It is a matter of some interest that a form of antiseptic which had been for so long a period a stand-by of the surgeon should suddenly come again into the foreground and gain as wide a popularity as it enjoyed in the pre-Listerian era. Early in the war the desire was often expressed for the *lotio sodii chlorinati* which was an application to infected wounds still familiar to some of the surgeons on active service. In the light of subsequent experience also it was astonishing that those who had been familiar with the transparent discharges resembling white-of-egg, seen in the hot dressings soaked in this lotion, should have been unaware or forgetful of the solvent action of the lotion on tissue fragments and the cellular element of pus. Had this been borne in mind the apparent abolition of pus from the surface of a granulating wound treated by the Carrel-Dakin method would have found a ready explanation.

In the British army interest was first re-awakened in hypochlorous acid and its combinations by the appearance of a paper entitled "Experimental observations on the antiseptic action of Hypochlorous Acid and its application to wound treatment," by J. Lorrain Smith, A. W. Drennan,

T. Rettie and W. Campbell of the Pathological Department of Edinburgh University. These investigations stated " that hypochlorous acid is a more potent germicide than its salts ; and further that it might be used either in the form of a gas or as a solution in water (eusol) for the treatment of wounds." They pointed out that it caused little or no harm to the tissues. that the effects produced by it were purely local, and that the decomposition products were devoid of toxicity. It was further claimed that application of solutions of the acid induced a flow of lymph, that fœtor was rapidly eliminated, and that if pain or local irritation occurred they could rapidly be controlled by reducing the concentration of the antiseptic.

If there was difficulty in procuring water, the use of a powder (eupad) was suggested which could be introduced into the gauze pad of the first field dressings, or could be dissolved in water to make the solution. It was pointed out that the constituents of the powder were inexpensive, easily procurable, and that the preparation of either the solution or the powder was a simple matter.

The following directions for the preparation of hypochlorous acid for use as an antiseptic were issued :—

(1) Eusol (0·5 per cent. aqueous solution of hypochlorous acid).

(*a*) To prepare this solution shake up 12·5 grammes of boric acid powder and 12·5 grammes chloride of lime (bleaching powder) with 1 litre of water ; allow to stand for a few hours, then filter.

This solution contains 0·5 per cent. free hypochlorous acid if the chloride of lime is in good condition. The latter must be dry.

(*b*) If scales and weights are not available an approximation may be made by measuring out 50 c.c. of boric acid powder and 35 c.c. of chloride of lime.

The powders should be measured loosely, not shaken down. If a cubic centimetre measure is not available an ounce measure may be substituted, in which case take 2 oz. boric acid powder to 1¼ oz. chloride of lime.

Take a Winchester quart, fill with water up to the shoulder line (approximately 2 litres), add the measured quantities of boric acid powder and chloride of lime, and shake vigorously for a minute or two, allow to stand for two or three hours, then filter.

(*c*) When the chloride of lime is supplied in ¼-lb. air-tight packets another method may be adopted :—

Cut one end of the packet off, extract the contents without damaging the packet. The chloride of lime weighs approximately 110 grammes. Fill the packet loosely with boric acid powder *twice*. This will give approximately 135 to 140 grammes boric acid ; the excess will do no harm. Mix the powders thoroughly. It is sufficient to crush the lumps of chloride of lime with a spatula or the fingers ; grinding is not necessary. This quantity will make 4 Winchester quarts of solution. To make up one Winchester quart, fill the packet with the mixed powders. Tap gently while filling. It will then hold approximately 60 grammes of the powder. Add this to the Winchester quart as above

described. This solution will remain efficient for about three weeks. It should be kept in coloured bottles. Stronger solutions if left do not keep. It is destructive to cloth and corrodes metals in contact with them. All instruments should be washed at once after use.

(2) Eupad (powder of equal weights of boric acid and dry chloride of lime). For use as a powder grind the chloride of lime to a fine powder, mix thoroughly with an equal weight of boric acid powder and keep in stoppered bottles.

After the lapse of ten months, a clinical report on the application of eusol was made by a committee appointed by the Medical Research Committee. It reported that eusol was a non-toxic, non-irritating and efficient antiseptic, the most essential ingredient being hypochlorous acid, but enough calcium biborate was present to render the solution feebly alkaline. It was claimed to be the most efficient antiseptic for use in military surgery, particularly during the period of progressive sepsis. It was further stated that intravenous injection of eusol had proved successful in several cases in combating general toxæmia. The solution, moreover, had been found capable of retaining its efficiency for a period of three weeks in the winter, or of one week in warm weather.

Eusol gained a rapid popularity both in the forward units and on the lines of communication and was very extensively employed. Eupad was found to be painful on primary application, irritating to the tissues, and moreover it had the common disadvantage of all powders that it tended to cake and to desiccate the wound.

Eusol was commonly employed for warm dressings, also as an irrigation fluid, and for interrupted or continuous baths. Captain J. Fraser at an early period made use of it in the initial treatment of "gas gangrene," and testified strongly as to the efficacy of hypochlorous acid solution in this form of cellulitis. He recounts a small number of cases, but examination of the histories shows that Fraser at this period had acquired a proper notion of the mechanical treatment necessary, and probably overstated the influence of the particular form of antiseptic application.

The fluid was also used in conjunction with Carrel's tubes and was not found to give any serious divergence in results when compared with the Dakin-Daufresne solution, except in its lesser degree of solvent power on necrotic tissue.

Intravenous injection of eusol was extensively employed at one period of the campaign, 60–100 c.c. being introduced in the treatment of toxæmia and septicæmia. It is impossible to say whether the results attained differed materially from those

Pregranulation stage of an aseptic wound (4 days). It was excised at a casualty clearing station and treated by the Carrel-Dakin method. The piece of fascia lata seen in the centre is necrosed and infiltrated with leucocytes, but smears made from it show that it is up to "suture standard." Note absence of pus, and all inflammatory reaction.

Granulation stage of same wound as shown in Plate V. (14 days). Carrel-Dakin treatment continued. The dead piece of fascia lata has almost completely separated. The wound is still up to "suture standard." Note colour of granulation tissue and regular ingrowth of epithelium.

which might follow the injection of an equal quantity of normal saline solution, and Dakin's observations support the view that any antiseptic action was minimal in degree, but many surgeons quoted individual cases in which they believed good results to have followed the infusions.

It is interesting to note that the old experience of Charles Watt in 1859 was revived, and hypochlorous solution was manufactured from solutions of sodium chloride and from sea water by the electrical method. The solutions produced in this manner proved themselves very unstable and little use of the process was made.

It may be stated that eusol fairly maintained the claims made on its behalf as an antiseptic solution. It is a more stable preparation than the older forms of hypochlorite solutions which it displaced, it is easily prepared, and it cannot be doubted that it will remain a permanent asset to the armamentarium of military and civil surgeons alike.

The Carrel-Dakin method of treatment is another method for the employment of solutions of hypochlorous acid in the treatment of infected wounds. The use of the Dakin and Dakin-Daufresne fluids, however, forms but a part of a procedure in which every detail of wound treatment was carefully considered and perfected. Thus, although the principle on which the method is founded differs in no sense from that of the antiseptic reservoir propounded by Lister, yet the details were worked out with a thoroughness which Lister himself must have regarded with approbation and admiration.

The success which attended its introduction and gradual perfection, while substantiating the opinion that any antiseptic employed must possess the quality of inhibitory or destructive powers towards the infecting organisms and at the same time be innocuous to the vitality of the tissues, demonstrated the fact that details in surgical technique, precautions designed to avoid the risk of the introduction of infective material by the surgeon himself, and a proper reliance on the natural process of healing, are factors of supreme importance in the avoidance of failure.

No doubt can exist that the introduction of the system and the results attained by its use demonstrated that the practice of secondary closure of open wounds which had been primarily infected might be far more generally resorted to than had ever been believed possible. Further, the success which attended the practice of secondary suture took no small part in encouraging surgeons to strive for the ideal aim of primary

closure and thus to eliminate all chance of the development of the conditions which had called for the institution of such methods as the Carrel-Dakin.

The main principle involved is that of constantly maintaining an efficient solution in contact with every nook and crevice of the wound. This is effected by the delivery of the antiseptic at stated intervals by means of the specially devised tubes, so that the loss of bactericidal power consequent on the combination of the hypochlorites with albuminous matter should be discounted.

The Dakin-Daufresne solution eventually employed was made in the following manner:—200 grains of bleaching powder, containing 24 to 28 per cent. of available chlorine, were shaken well with five litres of water and allowed to stand for eight hours. In a second vessel 94 grains of dry sodium carbonate and 86 grains of sodium bicarbonate were mixed with five litres of water. When the latter were dissolved the resulting solution was added to the bleaching powder suspension and shaken. When the mixture settled the supernatant fluid was syphoned off and tested. It should contain 0·45 to 0·5 per cent. of sodium hypochlorite.

The details of the method are so fully set forth by Carrel and Dehelly that further details are unnecessary, but the history of the introduction of the method into the practice of the medical service of the British army may be shortly recounted.

Early in the year 1915 visits were made to Compiègne and the method was discussed with Carrel and Dakin. The excellence of the equipment and the somewhat complicated arrangements at Compiègne gave rise to the impression that it would not be easy to introduce the system into the military hospitals of the British army. Nevertheless the excellent results that were being attained at that period could not fail to impress the surgeon, and limited trials were carried out by many individuals with more or less success. Meanwhile modifications, extensions and simplification of the method were steadily being carried on at Compiègne, Dr. Carrel and Dr. Dakin giving the British surgeons information upon all these points.

In May 1916, two wards in No. 26 General Hospital at Etaples were allotted for a more exact trial of methods of wound treatment, and Captain J. T. Morrison and Major Sydney Rowland, as surgeon and pathologist respectively, were put in charge of the patients. For a few weeks they also had the great advantage of the presence and help of Dr. Dakin.

Arrangements were made whereby the patients might be kept a sufficiently long period to allow of exact observations being made, and for the wounds to heal up completely. An ambulance car was attached to the unit in order that the medical officers might travel to a casualty clearing station at Aubigny, select suitable cases for trial, prepare and dress the wounds, and bring the patients down by road to the observation wards.

This system was maintained for some months, but in consequence of the difficulties experienced in working two wards in a large unit, in November 1916 the Joint War Committee of the British Red Cross Society and the Order of St. John generously provided a small special unit, consisting of two wards of twenty beds each, two small wards for two beds, an operating theatre, a laboratory and a kitchen. After a long succession of delays due to the difficulty in obtaining the necessary materials for building and the equipment, this surgical observation hut was opened in June 1917.

Meanwhile Major Sydney Rowland, to the great grief of his colleagues, died of cerebro-spinal meningitis on March 5th, 1917. The staff which thenceforth worked the unit consisted of Captains J. T. Morrison, J. N. J. Hartley and E. F. Bashford, assisted for part of the time by Lt.-Col. Seymour Barling.

Mention is made of the surgical observation hut in this place, on account of the influence it had in the popularization and proper execution of the Carrel-Dakin method on the lines of communication. It was not intended, however, that the work of the staff should be limited to this particular form of treatment, but should extend generally over the whole field of wound treatment. This object was carried out with the result that much exact information was obtained on the process of healing and on the relative value of the physiological method, the salt pack method, flavine, dichloramine T. and other substances.

While matters were being advanced on the lines of communication, progress in the same direction was being made in the forward units, and in June 1916, a meeting of consultants was held at General Headquarters at which a memorandum for guidance was drawn up, and later circulated generally. In the first instance the trial was, however, limited to certain units at the front, and an attempt was made to ensure the cases being sent down to definite units on the lines of communication prepared to receive them. This precaution was necessary because it had already been found that numbers of

cases emanating from the front line generally had been sent down either imperfectly prepared, or suffering from want of suitable care during the period of transit; moreover, such cases sometimes came into the hands of surgeons unacquainted with the principles or technical details of the method.

A short abstract of reports from two of the units on the lines of communication will serve to show the results attained as a sequel to these measures. They are given separately as the differences in the two reports illustrate the divergence of opinion and practice common to separate units in military service.

The first report deals with 138 cases, of which 90 were wounds confined to the soft parts. In 48 the bones were also involved.

Of 100 of these cases the preliminary treatment was considered satisfactory in 49 instances, unsatisfactory in 51. In 22 of the latter, either the tubes were too few in number, or the delivery holes too large. In the remaining 29 the preliminary preparation of the wound was defective, either by too limited opening up, incisions badly placed, or the non-removal of foreign bodies. In 63 cases the wound was able to be sutured secondarily, and in 53 of these perfect healing resulted. In the cases of wounds of the soft parts the average time of closure was the eleventh day.

In 29 cases the following secondary operations were needed, amputations 4, excision of joint 1, for secondary hæmorrhage 3, sequestrotomy 7, incisions and removal of foreign body 14. Two patients died, one after amputation and one from secondary hæmorrhage.

The further clinical progress of wounds not sutured was satisfactory in 56, and unsatisfactory in 19 instances. Seven compound fractures of the femur were included, four of which were closed, two progressed satisfactorily and one unsatisfactorily. Of six compound fractures of the tibia one was closed, two more with the application of B.I.P., two progressed satisfactorily, and one was subjected to amputation. Of ten compound fractures of the humerus two were closed, four progressed satisfactorily, and four did badly, one requiring amputation.

In the second series of 126 cases, 87 were wounds confined to the soft parts and in 39 the bones were involved.

The preliminary treatment was reported satisfactory in 103 instances and unsatisfactory in 23, the same defects being noted as in the first series.

Forty-three wounds were closed, of which 34 were evacuated to England "progressing satisfactorily." The average date of closure was the 14th day.

In 23 cases the following secondary operations were needed, amputations 5, sequestrotomy 1, drainage of knee-joint 2, incisions and removal of foreign body 20.

Five patients died, 1 from tetanus, 1 from gas gangrene, and 3 from septic absorption.

The further clinical progress of wounds not sutured was satisfactory in 70, and unsatisfactory in 13 cases. Seven compound fractures of the femur were included. Of these, one was closed, two progressed satisfactorily, two did badly but improved, and two died, one after amputation. Of eight compound fractures of the tibia none were closed, five progressed satisfactorily, and in three, amputation was necessary. One compound fracture of the fibula and one of the ulna progressed satisfactorily. Of four compound fractures of the humerus three did well and one was amputated.

These results, although not ideal, were a great improvement on those generally obtained at the time, and it may be specially noted that only one case of gas gangrene and one of tetanus occurred amongst 264 patients. The results differed in accordance with the familiarity with the method acquired by the surgeons of the casualty clearing stations and it was noteworthy that the unit which first commenced to use the treatment did not send down a single wound which had to be classified as imperfectly prepared.

At a slightly later period, although the results were not published until 1918, a series of 200 consecutive wounds was dealt with. These cases were divided into two classes, "A" cases, or those operated upon within twenty-four hours of the reception of the wound, and "B" cases or those in whom either no primary cleansing operation had been done or in whom it had been undertaken after an interval of more than twenty-four hours.

	"A" Cases.	"B" Cases.
Suture Standard reached in	82·5% in 12 days	64·4% in 15 days
Suture performed in	77·5% in 13·6 days	53·5% in 17 days
Healed before Evacuation	67·5%	44·2%
Average Duration of Treatment before Healing	28·2 days	33·6 days

It should be noted that at this period operative measures were undertaken only in response to some urgent indication during the first ten days after the arrival of patients in the hospitals on the lines of communication.

A series of cases in which excellent results were obtained in a

voluntary hospital maintained by Millicent Duchess of Sutherland, was also recorded by O. G. Morgan, F. D. Saner and E. G. Schlesinger. Some variations in the type of method were employed, but the principles were maintained. It is of interest to note that the authors not only place the "proteolytic" action of the Dakin-Daufresne solution in the forefront, but state further, "it is perhaps unfortunate in a sense that in a test tube this fluid is possessed of a high bactericidal power. By thus attaining rank as an antiseptic, it has shared any criticisms of these substances, and has had its claims based on a fortuitous property which would appear to us after considerable experience of its use to play a quite secondary and relatively unimportant part in its action." This opinion coincides with one already expressed by Dr. Kenneth Taylor, as to the value of the solvent action of the solution, and offers a much more simple explanation of its efficacy than the different theories of specific action that were from time to time assigned to it by other surgeons.

Major J. S. Dunn, in a report comparing the conditions of cases arriving at a port of embarkation and treated by different methods, speaks as follows of those in whom the Carrel-Dakin method had been employed. They "invariably arrived in good condition, and if a complete operation had been performed and the technique of the dressing strictly carried out, it was often difficult to realize that the patient was suffering from a dangerous wound."

In January 1916, a paper by H. D. Dakin, J. B. Cohen and J. Kenyon of the University of Leeds, on the preparation, properties and uses of chloramine, stated that chloramine belonged to a series of compounds containing chlorine linked to nitrogen and possessing strong germicidal properties. Substances containing this type of linkage were studied because analogous compounds were believed to be formed by the action of the actively germicidal hypochlorites upon proteins and some other nitrogenous cell constituents. The germicidal action was stated to be intense, and when tested against the ordinary organisms of infected wounds it was found to be almost as powerful as an equal weight of sodium hypochlorite. It was not corrosive even in concentrated solutions. It neither precipitated nor coagulated proteins, such as blood serum, a property of great practical importance in the treatment of infected wounds. It was pointed out that being a highly reactive substance, it should not be mixed with other antiseptics. Both alcohol and hydrogen peroxide were decomposed by it

Practically the matter was stated as follows: Chloramine represents an active antiseptic containing a store of chemically combined chlorine in a form which is quite stable and non-irritating under ordinary conditions. But when brought in contact with proteins and similar cell constituents containing basic (NH_2) groups, it acts as a chlorinating agent, losing its chlorine to the basic substance, and thereby exerting its antiseptic action as needed.

Chloramine was largely used as a powder, in solution, and as an ointment combined with stearate of soda. It was also used in the form of impregnated gauze for plugs. In all these forms it proved itself a useful antiseptic, but it was never so widely employed as the hypochlorite solutions.

At a later period another substance, dichloramine T, belonging to the same class was recommended as a substitute for chloramine. A careful study of fifty cases of infected wounds treated by dichloramine T was made at the surgical observation hut at Etaples. The results obtained may thus be summarized: Dichloramine T although resembling the hypochlorites in its germicidal action, differs in many other respects. It has little disintegrating power on necrotic tissue; it is a powerful coagulator of albumen, and even in the strength of 1–1000 precipitates some of the albumen present in serum. It is very sparingly soluble in water, hence an oily solution is made from which the antiseptic passes slowly to the wound surface. A more prolonged action is thus afforded, in lightly infected wounds for about twelve hours, in heavily infected wounds for a shorter period.

In the fifty cases recorded the dichloramine treatment was commenced from two to six days after the infliction of the wound, subsequently to a cleansing operation followed by one or other of the established modes of treatment, mostly Carrel-Dakin or B.I.P. A two per cent. solution in chlorinated eucalyptol diluted with chlorinated paraffin was used. The wounds were dressed daily with loose packs of lint lightly wrung out of the dichloramine oil. In certain cases where there was much purulent discharge, a piece of tubing was employed to renew the solution in the deepest parts of the wound every eight to twelve hours. The clinical results obtained, when judged from the standpoint of ordinary experience, would be classed as good, the wounds passing fairly quickly through the usual stages. Sloughs separated and granulation of a moderately bright red colour soon appeared. Pus formation was as a rule small, and the spread of infection

to surrounding parts was not common. Epithelial growth at the wound margins was somewhat slow. The wounds did not attain the bacteriological standard in good time, and if such were closed before the standard was reached the results were no better than is usual when clinical grounds alone are relied upon without reference to bacteriological control. Skin irritation was troublesome. When compared with the Carrel-Dakin results, the latter show that 20 per cent. more were able to be sutured, and 32 per cent. more of the wounds healed before the evacuation of the patients.

The following conclusions regarding the use of dichloramine T were arrived at :—

(1) The treatment is simple of application, and the claim to prolonged activity of the antiseptic is established.

(2) If the treatment needs to be prolonged, the ingrowth of skin is retarded, and granulation tissue tends to become disorganized.

Though better than some other methods in vogue, dichloramine T oil did not yield the improvement on Dakin's solution that was anticipated ; perhaps because it was neither innocuous to granulation tissue, nor a solvent of dead tissue, perhaps possibly because an oily application was not so efficacious as a watery solution in the treatment of wounds. In spite of the above disadvantages, however, dichloramine T did find a certain amount of favour, especially from the lesser frequency of change of dressing which resulted from its use.

Early experience in the treatment of infected wounds by the application of iodoform had been to the effect that in many dirty septic wounds a distinctly favourable influence was exercised. Iodoform, however, was not very largely used and its choice depended mainly on the individual surgeon. In August 1916, a communication was received from Sir Alfred Keogh enclosing a description of the method devised by Rutherford Morison of treating the previously properly prepared surface of infected wounds by a paste of bismuth, iodoform and paraffin, known as B.I.P., resembling in composition that introduced by Beck for the injection of chronic suppurating sinuses. At this time also, Morison published a paper in which he arrived at the following conclusions :— (1) The treatment of septic wounds in the manner described makes possible healing by " first intention " under infrequent dressings, and without drainage further than that allowed for through gaps left by interrupted sutures. (2) Acute abscesses, opened, cleaned, filled with B.I.P., and closed by interrupted

sutures can heal by first intention without further pus formation. (3) It appears to be safe to plate compound fractures by adopting the method described.

A trial was made in two of the hospitals at Etaples without very satisfactory results, and the method did not begin to grow in favour until towards the end of 1916, when it was considered advisable to circulate the following memorandum.

"The Treatment of Infected Suppurating Wounds by Professor Rutherford Morison's method.

This method has rapidly gained favour in dealing with infected wounds when the infection has localized itself to the seat of injury.

It has not until now been adopted for the treatment of recent wounds and obviously is open to certain risks which are not calculable, both with regard to the more rapid absorption of the media by fresh tissue and the danger of obstructing exit of discharge from the wound. It is therefore to be used with caution, and never to wounds the entire surface of which is not open to inspection.

The method consists in the following steps :—

(1) For the first dressing the patient is anæsthetized, the wound is covered by gauze wrung out of 5 per cent. carbolic lotion, and the surrounding area of skin is then cleansed with the same lotion.

(2) The wound is opened up freely, if possible sufficiently widely to allow of inspection of the cavity, but with due regard to nerve trunks and muscular branches to nerves. The cavity is cleansed by dry mopping with sterile gauze, Volkmann's spoon, or, if any obviously dead tissue is present, the knife or scissors. All foreign bodies are removed.

(3) The wound cavity and the surrounding skin are mopped out with methylated spirit. Cotton wool mops introduced by forceps are used for this purpose.

(4) The iodoform and bismuth mixture is rubbed into all parts of the wound with dry sterile gauze, and any excess of the paste removed.

(5) It is probably unwise to close quite recent wounds, but wounds of longer standing may be closed either by strapping or preferably by interrupted sutures. For the latter purpose, thick sterilized silk soaked in tincture of iodine and tied through drainage tube by Stiles's method is recommended. In dirty wounds the sutures should not be introduced too closely, but no large gaps need be left. All wounds should be closed as far as possible without tension at the first operation or at the first dressing.

(6) The wound is dressed with sterile gauze covered by an absorbent pad held in position by adhesive plaster and a bandage.

(7) Redressing is not required for some days or weeks if the patient remains free from pain and constitutional disturbance ; but, should discharge come through, the stained portion of the dressing must be soaked with spirit and a gauze packing wrung out of the same applied as a further covering.

(8) Redressing is very simply done. After removal of the old dressings the wound is covered with a pad soaked in spirit. With similar dossils of wool held in forceps the dirty sticky-looking discharge is then wiped from the surrounding skin and a clean dressing is applied, additional mixture being spread upon the surface if required.

(9) Symptoms of iodoform or bismuth poisoning have been occasionally observed and should be recognized as an indication for cleansing the wound and discontinuing the application. (Iodoform—rise

of temperature and pulse rate, delirium or apathy, red skin rash. Bismuth—emaciation, bronzing of the skin, diarrhœa, blue patches on the gums or about the mouth, or even ulceration. Such signs may appear after the wound is healed.)

(10) The wounds occasionally discharge profusely a slimy purulent fluid, and Professor Morison regards this as an indication for the removal of the paste and the adoption of some other form of treatment.

(11) In dealing with suppurating joints, a different procedure is recommended by Professor Morison. The joint is freely opened and the pus gently expressed, about two drachms of the paste is then ladled into the cavity, the opening closed, by interrupted sutures, and the medicament is distributed by gentle massage of the closed joint, all washing or scrubbing of the synovial membrane being strictly avoided.

(12) The mixture is compounded as follows :—

Iodoform	16 oz.
Bismuth subnitrate	8 oz.
Liquid paraffin	8 oz.

The powders are mixed together in a mortar and the liquid paraffin incorporated.

The quantity of liquid paraffin required varies according to the bulk of the powder, the bismuth in particular being liable to considerable variation in bulk. A sufficient quantity should be used to form a mixture capable of being spread, which should be rubbed down in small quantities at a time with a spatula on a slab, so as to ensure freedom from grit and any dry particles of powder."

Circulation of the memorandum was followed by a rapid increase in the use of the method, not only in the hospitals on the lines of communication, but also in the forward units. In the main the directions laid down were adhered to, but the tendency to close recent wounds treated by B.I.P. was responsible for exciting considerable criticism of the method by surgeons working in the general hospitals on the lines of communication. It became evident that primary closure of wounds treated by B.I.P. could only be profitably and safely resorted to in superficial and minor injuries; in deep and irregular wounds and in those complicated by fractures of the bones it was inadvisable and sometimes dangerous. It was observed that even minor wounds which had apparently healed broke down again in some instances, and in the case of deeper wounds this was not at all uncommon. In these a part of the cicatrix opened up, iodoform and bismuth were discharged, and a sinus developed which did not heal until the whole of the powders had escaped.

As to other ill-effects, most were due to errors of technique. For instance, some wounds were closed without removing foreign bodies present, and in others too much of the compound had been introduced and left in the wound cavity. Putting aside the few cases of individual idiosyncrasy, these errors

were responsible for the instances of iodoform and bismuth poisoning. Toxic symptoms, indeed, were far from uncommon at one period, and a few deaths occurred. The symptoms were more often those of bismuth poisoning than of iodoform, and in the former the signs were often local and unaccompanied by any constitutional symptoms.

Wounds treated with the compound, lightly packed with gauze wrung out in spirit and covered with a pad and bandage at the forward units, came down in good condition and proved very suitable for secondary suture after a period of some days, usually ten or twelve. The results attained when the treatment was adopted at a later stage in the general hospitals corroborated those claimed by Morison himself and those obtained at the Endell Street Hospital in London.

The method was shown to be safe if the precautions laid down were observed; it avoided frequent dressings, and thus saved both time and expense; it spared the patient the pain attendant on frequent dressing of his wound, and it ensured rest to the injured part.

A thorough investigation of a number of cases was made in the surgical observation hut at Etaples, and the relative advantages and disadvantages of the method cannot be better expressed than in the words of Captain J. T. Morrison.

"Underlying its use is again the desire to apply to the wound an antiseptic —admittedly a weak one—which does not disappear or lose its potency. In this treatment, even more than in other presumed antiseptic methods, one feels compelled to seek for other factors in order to account completely for the success attending its use. In the case of B.I.P., attention is at once directed to three additional factors to which much of the undoubted value of the method must be assigned. Dressing of the wound is infrequent and this carries with it advantages quite apart from the important saving of labour it secures. There is, first of all, the important tissue splinting obtained by the immobilization of the dressing for several days, and the resulting protection afforded to the delicate vascular loops on the surface of a re-acting wound. There is, secondly, the fact that the infrequency of the exposure of the wound means so many fewer opportunities for cross infection. Thirdly, a study of the histology of wounds treated by B.I.P. makes clear that the growth of the granulation tissues is slow, opposed surfaces do not readily unite and consequently drainage from all parts of the wound is not so liable to be interfered with. In other words, infected material is not so likely to become locked up in crevices, and coming thus under tension to spread along the neighbouring tissue planes.

Unfortunately these advantages have their corresponding disadvantages. The very slow progress of the processes of repair involves delay in the separation of necrosed tissues (which it is not always possible to cut away) and, what is still more unfortunate, when once sepsis has become thoroughly established in a wound, the comparatively poor vascular supply to the surface prevents the full use being made of the body's natural methods of cure. It also implies delay in the final healing of the wound. Hence it is that Morison recommends that when the wound becomes clean, granulating and superficial, B.I.P. should be discarded and ordinary daily dressings used."

Allowing the full justice of the paragraphs quoted, the fact that union is slow, that sutures must be retained for long periods, and that when sinuses once form they do not close until the whole of the iodoform and bismuth has escaped, it has on the other hand been abundantly proved that many old deep wounds and especially compound fractures have healed during treatment by this method in far less time than by the ordinary methods employed for the cure of chronic suppurating wounds, with sparing of pain to the patient and great economy of expense and labour. Rutherford Morison claims also that in the cases of repairs of fractures the application favours and stimulates osteogenesis.

It need only be mentioned that when radiography is needed the use of the paste is inconvenient, definition of foreign bodies or the bones being greatly or totally obscured.

In January 1917, a communication by Browning, Gulbransen, Hennaway and Thornton, of the Bland-Sutton Institute of Pathology and the Middlesex Hospital, on the use of flavine and brilliant green as powerful antiseptics in the treatment of infected wounds, roused the hopes of many that an ideal antiseptic had been discovered amongst the group of aniline dyes. Brilliant green was first introduced into practice in France by Captain A. Leitch, and Captain W. H. Hey used a solution to which boric acid was added and also a paste composed of boric acid 11 ozs., French chalk 1 oz., liquid paraffin 8 ozs., and brilliant green 17½ grs., but neither mixture was widely used.

For the use of flavine as an antiseptic it was claimed :—

(1) That it possessed powerful bactericidal and antiseptic properties, enhanced rather than diminished by admixture with serum, thus differing from all the powerful antiseptics in common use.

(2) That in the presence of serum it had proved itself the most potent bactericide of a number of substances investigated (including carbolic acid, mercuric perchloride, chlorine water, eusol, Dakin-Daufresne solution, di-chloramine T, iodine in potassium iodide, and a series of aniline compounds), for staphylococcus and *B. coli*, and equally efficient for the destruction of enterococcus and anaërobic organisms such as *B. œdematis maligni*.

(3) That in relation to its bactericidal power it was very much less detrimental to the process of phagocytosis, and less harmful to the tissues than the other substances; hence it

could be employed in much higher concentration without damaging the tissues or interfering with the natural defensive mechanism.

(4) That the above claims were substantiated by clinical results.

It was maintained that in the treatment of septic conditions by these substances, the duration of the infective process was in general reduced by at least one half, that the stimulus to connective tissue to form granulations was an outstanding feature; and that these antiseptics could be applied in considerable amounts with a minimum of interference with the normal tissue functions. Also, in all injuries of recent origin before there had been time for evidence of infection to appear, it was believed that almost all would heal by first intention provided thorough cleansing with the antiseptic had been carried out.

The original investigations of the properties of flavine were carried out with a sample prepared in the laboratory of Ehrlich, and it became necessary to work out the process by which a large stock could be produced. Barger and Ewins performed the latter duty in the chemical laboratory of the Department of Bio-chemistry and Pharmacology of the Medical Research Committee, and arrangements were then made for the commercial production of the substance. In view of the great importance of securing a sufficient supply for the military hospitals at home and abroad, the primary output was controlled by the military authorities, and this control was maintained until October 1917, at which time it became no longer necessary, as the substance had not fulfilled the expectations at first aroused, and a sufficient supply to meet the needs of the army was no longer in doubt. Small quantities of flavine arrived at the casualty clearing stations towards the end of April 1917, and a series of cases was treated by Major Drummond with the collaboration of Major McNee. Their investigations furnished evidence that wounds, after proper mechanical disinfection followed by the application of solution of flavine of the strength of 1 in 1,000, could be immediately closed and primary union attained.

Widely open wounds were treated by light gauze packs impregnated with 1–1,000 solution, followed by the occasional instillation of a solution 1–5,000 in strength. In deep and narrow wounds instillations were made by Carrel's method every four hours. In these classes of cases the absence of any inflammatory reaction and the limited amount of

discharge from the wound was very striking, more especially as bacteriological examination showed that the solutions did not rapidly sterilize the surface of the majority of wounds.

The claims that flavine was not toxic, that it tended to prevent the spread of infection and of suppuration were substantiated, but on the other hand the influence of the solutions was found to be detrimental to the rapid development of granulation tissue or the spread of epithelium. Hence it was recommended that the application of flavine should be limited to the first three or four days, and then replaced by some other form of treatment. Little material exists from which to draw conclusions as to the further course of the cases treated primarily at the casualty clearing stations. The following report by Major J. S. Dunn, however, probably refers to some of the cases included in the report by Drummond and McNee. "A number of the cases arriving at a port of embarkation had been treated with flavine and Z paste, and had been retained at the casualty clearing station from six to ten days. The results were exceptionally satisfactory. The wounds in nearly all were closed; in some the sutures had been already removed when the patients reached the general hospital, in others they were taken out on arrival. Only two cases showed signs of inflammation, one of which was a case of severe multiple wounds. Where the patient can be kept under observation, and an early and complete operation can be performed, this seems an ideal method of treatment."

A careful series of experiments was carried out at the surgical observation hut at Etaples on cases treated primarily by other methods which reached the lines of communication in the stage of developed infection. In this investigation the following lines of treatment were followed. The skin was carefully cleaned with neutral sodium oleate solution, and covered with sterile strips of bandage cloth permeated with sterilized vaseline. The wound was swabbed out with gauze wrung lightly out in flavine solution, all obviously necrotic tissue was cut cleanly away, and every recess was then packed with strips of dressing soaked with the flavine solution (1–1,000). In a few cases where long tracks or pockets difficult of access had to be dealt with, Carrel's tubes were used for the purpose of a four-hourly instillation of the flavine solution, 10 c.cm. per tube. A solution of the same strength (1–1,000) was used throughout the whole course of treatment. One or two layers of bandage cloth impregnated with vaseline were used as an impermeable covering to the wound.

Wound of soft parts of left arm, involving fascia and muscles. The wound had received no previous treatment (mechanical or chemical); treatment with flavine commenced 30 hours after wound. Drawing made 7th day, size of wound is unaltered, margins are unchanged, no growth of epithelium having occurred. The surface is clothed with a thick fibrinous exudation beginning to separate and show signs of subjacent granulation tissue. A ring of greenish coloured material possibly stained with altered blood pigment surrounds the central yellow patch of lymph exudate. The soft parts of the arm have remained normal with no signs of spreading infection in the limb. The sharp rigid margination of the wound is striking.

Same wound as Plate VII. on 21st day of treatment. The surface is evenly covered with very fine granulations characteristic of wounds treated with flavine (1 in 1,000). The wound had become infected with *B. pyocyaneus* four days previously and had then cleared rapidly. There is no change in the size of the wound and only a faint trace of a blue epithelial line is apparent. Patient was evacuated to England on the fortieth day, when the wound had contracted to a fourth of the original size. It had been strapped for some days. Films still showed many Gram negative bacilli, and probably *B. pyocyaneus*.

The wounds chosen for observation were not of great gravity, on account of the experimental nature of the treatment; almost all had been treated previously at the front by the Carrel-Dakin method within twenty-four hours of reception of the wound, and in the majority of instances very efficiently.

The treatment was carried on continuously until either the wound became ready for secondary suture, or until after three weeks' treatment it had definitely failed to attain the necessary standard for closure. In a few cases the treatment was stopped earlier in the patient's interest.

The clinical history of these wounds is as follows. When first seen, as a rule two or three days after the wound was received, the surface was still red and raw. In pockets and recesses a little pus might be observed; sloughs were beginning to show grey and yellow, and sometimes there would be a more or less offensive odour. The previous treatment, however, had been so good that the amount of sloughing tissue was usually slight, and most of the cases were not really heavily infected. Twenty-four hours after the application of the flavine dressing the surface was stained a bright yellow colour, especially where fascial or tendinous structures were exposed. Pus was usually very small in amount, and where it had been present it usually diminished rapidly in quantity. The surrounding tissues in most cases remained healthy, and free from œdema or infiltration. Any spreading infection that already existed generally subsided quickly. In two cases secondary abscesses developed and in a third infection spread along the tendon sheaths.

Once established, these appearances (Plate VII) remained characteristic of wounds treated with flavine for two or three weeks. From then onwards the yellow surface, mainly due to the deposition of a tough layer of plastic lymph, gradually disappeared, being replaced by small granulations of a pale pinkish colour (Plate VIII). It was very noticeable that when a heavy growth of organisms was present on the wound surface this change took place much more rapidly, and in not more than four or five cases really good small dark red granulations were seen. Throughout this time ingrowth of epithelium was very slow, starting generally in the course of the third week, but prior to that the wounds remained with sharp edges, having almost a punched out appearance.

The bacterial flora was watched continuously, the suture standard of Carrel being used as the indication for secondary closure of the wound. It was observed that the commonest

organism to outlive the others was a Gram-negative bacillus, and not cocci or streptococci as is the case with the Carrel-Dakin method. The following table shows the comparative rapidity with which wounds already infected, treated by flavine or the Carrel-Dakin method, became ready for secondary closure.

Table of Average Results.

	Flavine.		Carrel-Dakin.	
	Percentage of Cases.	No. of Days.	Percentage of Cases.	No. of Days.
Temperature Normal ..	86	8·8	94	11·7
Suture Standard reached ..	38	15·6	68	12·6
Suture performed	34	17·0	54	14·9
Healed	22	26·5	56	28·6
Evacuated Unhealed ..	78	24·0	44	36·8
Secondary Hæmorrhage ..	4	—	0	—
Secondary Amputation ..	2	—	4	—
Mortality	0	—	0	—

The temperature reached normal distinctly earlier, as a rule, in the flavine group, but the percentage of failures to reach the normal line while under treatment with flavine was somewhat greater. Under the influence of flavine only 38 per cent. of the cases attained the standard required for suture, which was in marked contrast to the 68 per cent. under treatment in the Carrel-Dakin series. The superiority of the latter is still maintained when one compares the number of wounds sutured and the percentage of patients evacuated to England healed.

In eight per cent. of the cases treated by flavine, irritation of the skin was noted. Redness and œdema developed around the wound, then an eruption of papules becoming vesicular. Cultivation from the vesicles was negative; in one case, the wound itself was sterile; and in six per cent. the complication was severe enough to demand a change of treatment.

Captain Bashford followed the clinical progress of the wounds by histological examinations. The original yellow pellicle was found to consist of coagulated blood and fibrin, the more deeply stained areas corresponding with the blood clot. On the third day a homogeneous layer, wanting in the characteristic structure of fibrin and curiously free from

leucocytes, clothed the surface of the wound. Beneath this, muscle fibres which had lost their staining reaction were embedded in hæmorrhages and a fibrinous exudate containing many entangled leucocytes. The whole structure was in a state of disorganization; there was practically no new formation of capillaries and scarcely a single muscle bundle showed any sign of regeneration. Some of the muscle fibres were fragmented by hæmorrhage, or heavily invaded by leucocytes.

At a deeper level still the muscle fibres were widely separated by exuded fibrin showing the typical network, and containing fewer leucocytes. The walls of the pre-existing blood-vessels were heavily invaded by leucocytes, and an undue proportion were thrombosed. From this depth normal tissues were approached.

On the seventh day interstitial haemorrhages formed the prominent feature. When the wound reached the condition suitable for closure the growth of epithelium was practically absent, and the granulations remarkably poor in blood-vessels. Moreover, the superficial tissue destruction tended to increase the depth to which the reaction of repair reached, and thus led to over-production of scar tissue.

Carrel, amongst other observers, commented on the destructive action of flavine on the tissues, and Fleming, in describing the physiological and antiseptic action of flavine, stated that it had a strong anticoagulent effect on human blood, which was, perhaps, an explanatory element in the occurrence of hæmorrhage, and that in a concentration of 1–2,000 it completely inhibited leucocytic emigration.

The introduction of flavine as an antiseptic agent gave rise to discussions only less energetic than those which accompanied the earlier comparisons drawn between physiological and antiseptic methods of wound treatment. The experimental methods of Browning were criticised, and clinical observers differed in their reports of treatment of cases. Examination of the literature of the subject warrants the following conclusions.

Flavine in solutions of 1–2,000, used as a primary application to wounds, in no way interferes with the occurrence of primary union. When used as a continuous application to open surfaces it is not a powerful antiseptic and is capable of causing a certain degree of tissue destruction. It is unsuitable for prolonged use, partly by reason of the pseudo-membrane which develops on the surface of the wound, and partly because it is opposed to the early development of healthy granulations.

The balance of opinion is also to the effect that the process of epitheliazation is slow and inefficient. All observers have agreed that it appears to limit the spread of infection into the tissues. It is not always non-irritating to the skin surrounding the wound, and it has been stated that the hands of the surgeon should be protected by rubber gloves, as an eczematous condition has been observed to develop.

A supply of "acriflavine" was obtained at the beginning of June 1917, and, later, samples of "proflavine," both being furnished by the Medical Research Committee. As was the case at the forward units, no important difference was observed in the action of either substance.

The procedures already dealt with may be said to exhaust the series which produced any serious and permanent effect on the treatment of wounds, but during the progress of the war, a large number of other methods was more or less extensively employed by individuals or single units. At the commencement of the war, solutions of iodine in spirit were regarded as an efficient disinfectant. They were largely used in the casualty clearing stations, and, at the general hospitals many of the wounds were painted with a 2 per cent. solution at each dressing. The application was painful, and it was rapidly realized that as an antiseptic, putting aside the action of the alcohol, it was practically useless. Hence these methods were entirely discontinued. As an application to the skin around the wound, however, it was more or less widely employed until the end of the war. The only disadvantage experienced lay in the fact that if the wounds were dressed with the regulation cyanide gauze, which was the common material in use during early days, blistering and dermatitis often ensued. This result was common enough to necessitate a general order to observe precaution in the matter. Its application in the form of an iodine bath (3 drachms to the pint), was the only one which maintained its ancient reputation, but this was gradually supplanted by solutions of the hypochlorites or hypochlorous acid as the latter gained general favour. As a means of disinfecting the skin also, picric acid solutions took the place of iodine in many units.

Rectified or methylated alcohol was used mainly as a constituent of solutions of iodine, or to cleanse and dehydrate the surface of the wound prior to the application of B.I.P.

The use of ether to any appreciable extent for the disinfection of gunshot wounds may be said to have followed the publication of a paper by Lt.-Colonel Sir Herbert Waterhouse.

He quoted 58 cases of peritoneal infection treated by instillation of some three to four ounces of ether into the cavity of the abdomen, with a mortality of two. Seven cases of acute arthritis and a small number of gunshot wounds were treated with success. In France the injection of ether was more largely employed in cases of arthritis than in other forms of injury, but many individual surgeons washed wounds of other parts with it. So far as has been ascertained, no careful observations on the subject were recorded in the case of wounds in general, but a large number of wounds of articulations were washed with ether at the time of primary operation.

In the earlier part of the war hydrogen peroxide solution was so largely used that great difficulty arose in obtaining a sufficient supply to meet the demand. It was employed for the lavage of wounds, to form a temporary moist dressing during the transport of patients and was even injected intravenously for the treatment of acute tetanus. The popularity of this solution depended in part on its well-known mechanical detergent action, and in this respect it maintained its reputation. The second reason for its use lay in the belief that it was specially useful as an inhibitory or destructive germicide for the anaërobic organisms. In civil practice stress had been laid on its special applicability as a lotion in wounds infected by the tetanus bacillus, and for some considerable period it was regarded as capable of inhibiting the growth of the microbes responsible for the cellulitis ending in gas gangrene. It was not only employed as a wash, but also freely injected into the limbs especially at the margins of the spreading infection. Time sufficed to show that the bactericidal powers of hydrogen peroxide were negligible in the treatment of either tetanus or gas gangrene, and its use was totally discarded as a specific antiseptic. Clinical experience in fact confirmed the laboratory pronouncement of Dakin that H_2O_2 is decomposed with the greatest ease by the enzyme catalase present in all tissues and in the blood cells, and hence acts for a trifling interval only. From this time forth the solution took its proper place as a wash for dirty or sloughing wounds, and as a useful local hæmostatic in cases of capillary hæmorrhage. Dakin quotes an instructive experiment performed by E. K. Dunham. Cubes of liver infected with *B. aërogenes capsulatus*, one millimetre in size, were incubated with hydrogen peroxide of moderate concentration without destruction of the organisms.

Potassium permanganate was at one time used as a powder applied to the surface of infected wounds, but the practice acquired small favour. As an antiseptic bath solutions were employed by some surgeons, but to a very limited extent compared with those of the hypochlorites, boracic acid or iodine.

Salicylic acid was employed to a limited extent as a powder or in combination with boracic acid as a constituent of the "borsal" recommended by Sir Watson Cheyne. It was recommended both as an antiseptic and as a solvent of sloughs. The application of these powders tended to desiccate the wounds, and a particularly unpleasant dark layer of sloughing tissue clothed the surface prior to the complete formation of the layer of granulations. Although salicylic acid was capable of inhibiting bacterial growth by reason of slow solution and hence continuous action, the results attained were not sufficiently good to atone for the disadvantages which were found to be inherent in the use of any form of powder.

A considerable supply of urea was sent out to France, on the ground that application of the powder to infected wounds controlled suppuration. This method of treatment received no support.

Boracic acid retained its popularity as the basis of lotions, medicated hot fomentations, and as an antiseptic element in continuous baths. It formed a component of borsal and, as already noted, was used in conjunction with brilliant green and as one of the constituents of eusol and of the original Dakin's solution. As an antiseptic of general utility it is not likely to be displaced in military surgery.

This remark on the general utility of boracic acid applies equally to carbolic acid, which in spite of its limitation as a bactericide is likely to remain in permanent use for hot dressings and lavage of wounds. One word must be added, however, as to its use in concentrated forms. In the early part of the campaign many cases arrived at the general hospitals in which it had been used as a primary sterilizing agent, and it may be definitely stated that it proved a universal failure. It is but fair to add that the mere application of pure liquefied carbolic acid to the surface of the wound by no means prevented early and successful union, an experience familiar enough to civil surgeons in the local treatment of tuberculosis. Many isolated cases of "delayed primary suture," even in the case of compound fracture, were successfully performed

by individual surgeons on the lines of communication long before either secondary or primary suture became recognized as capable of extensive utilization. A combination of carbolic acid and camphor was often used in these instances, especially by Canadian surgeons.

During the war there was considerable difficulty in procuring glycerine in any quantity, but it was used occasionally to aid the physiological method, and also to maintain moisture in the dressings. With regard to its use in combination with antiseptics, attention may usefully be drawn to a communication by Miss Goodrich in which evidence is furnished that such combination materially diminishes bactericidal power on the part of many antiseptics.

A saturated solution of glucose in 1 in 80 carbolic lotion was suggested by Captain H. B. Whitehouse, on the ground that such a solution possessed a greater "drawing power" than Wright's hypertonic saline.

The use of magnesium sulphate as a method of treatment was partly based upon the work of Colonel Sir A. Wright. A saturated solution (mag. sulph. 40 oz., glycerine 10 oz., water 20 oz.), of magnesium sulphate was employed. Major A. E. Morison had for some years employed the solution as an antiseptic application in civil surgery, and obtained results in military surgery which exceeded his most sanguine expectations. The method was little used in France, but the painless character of the application was a feature of some importance.

Petrol was occasionally used as an antiseptic in the early days of the war. Liquid paraffin was also used by individual surgeons to a small extent, and its "dielectric" powers were dwelt upon by Colonel H. M. W. Gray. Its most important application was as a constituent of B.I.P.

A preparation of 10–20 per cent. of glycerine and ichthyol was used by a few individual surgeons, mainly as a result of its recommendation by Major Duggan.

The sealing of wounds by mastisol gained little favour during the war, in spite of the popularity it enjoyed in the Russo-Japanese campaign.

Mencière's wound embalmment was a method which gained no favour in the British Army, although occasionally resorted to. The procedure consisted in washing the prepared wound successively with three antiseptic solutions. (H_2O_2 1–3, solution of mercuric chloride 1–1,000, solution of carbolic acid 1–40). After this initial preparation, designed with a view to

utilizing the specific action of the three antiseptics, a solution composed of iodoform grs. 10, guiacol grs. 10, eucalyptol grs. 10, balsam of Peru grs. 30, ether grs. 100, was applied to the surface, and wicks soaked in it were used to provide drainage channels. It may be recalled that balsam of Peru was used somewhat frequently for septic wounds in the earliest stages of the campaign and was looked upon with favour.

Familiarity with the use of picric acid in the treatment of burns in civil life, its known antiseptic and analgesic properties, encouraged the hope that it might prove a useful substance for application to gunshot wounds. The tendency of the solution to desiccate the wound was found to be a real objection to its use. In the later stages of the war, solutions of 3–5 per cent. in alcohol were extensively used for disinfection of the skin in place of solution of iodine, and for this purpose proved as satisfactory as they had already been found in civil practice.

One of the most interesting and instructive experiences of the war in relation to the value or superfluity of antiseptics is furnished in a paper by Captain J. B. Haycraft regarding the use of soap and water. He formed the following conclusions.—

"(1) Soap solution easily permeates and comes into contact with the whole surface of the wound. It acts as a mechanical cleansing agent, washing away all debris.

(2) In deep and complicated wounds, where complete excision of the surface is impracticable, wounds treated with soap solution* heal better than if an antiseptic such as eusol or B.I.P. had been used.

(3) The cases need to be dealt with a few hours after the wound is received, and after thorough mechanical disinfection.

(4) Compound fractures of the upper extremity practically always do well. Of three fractured femurs treated, two healed by primary intention.

(5) No wound thus treated can be safely evacuated in less than seven days.

(6). In cases in which primary closure is impracticable, a soap pack may be introduced and left untouched for five to seven days. When the pack is removed a 'beautifully healthy' wound is left."

* Sapo durus 1, hot boiled water 20; the soap is cut into shavings and dissolved. When required for use the solution is mixed with an equal volume of sterilized water.

A number of the cases dealt with in Haycraft's paper arrived at the general hospitals in a condition thoroughly warranting his conclusions.

No extensive experience of the helio-therapy method of treatment was obtained in the British Army in France. Under favourable circumstances, which were few, septic wounds undoubtedly did well. It is of interest to add, however, that some observations made by French surgeons showed that under suitable conditions the period necessary for healing of

individual wounds could be estimated and measured with the same degree of accuracy as Carrel had shown was the case with his method.

The General Progress of Wound Treatment.

The preceding account of wound treatment deals mainly with the local methods which were from time to time adopted at the general hospitals on the lines of communication in France, and there is no reason to assume that these differed either in sequence or nature from what were in use in other theatres of the war apart from special difficulties of transport by land and sea and variations of climate. This opinion is sufficiently well supported by such publications as have appeared. It remains to consider briefly, therefore, the actual results which may be attributed to the various methods, and to estimate the value of such advances as may be claimed to have been made.

It may first be broadly stated that the basic principles which should guide the surgeon in the treatment of a gunshot injury have not in any sense undergone material modification. The dominating factor in the healing of the wound, the natural physiological process of repair, has again asserted itself, and the surgeon as a healer of wounds retains the subordinate position appropriate to one who essays to modify or control the course of vital action. It has been more and more clearly demonstrated that the province of the surgeon is restricted to striving to eliminate or nullify the extraneous influences which tend to distort or interrupt the process of repair.

The primary condition laid down by Hunter that " the first and great requisite for the restoration of wounded parts is rest, as it allows that action which is necessary for repair to go on without interruption," may possibly be considered at the present day to take a secondary place to protection of the tissues from infection. None the less, the importance of the condition has been exemplified as in all previous campaigns, and although confidence in its truth could need no strengthening, yet the experience gained in the war has led to great advances in the provision of means by which the maximum of rest can be ensured in the treatment of gunshot wounds.

The improvements have been in two directions which may be considered as general and local respectively. When transport by motor ambulance cars was introduced, not only was disturbance of the injured part diminished but the duration of the disturbance was materially shortened. Meanwhile the

vitality of the patient—an all-important factor in the future progress of the wound—could be conserved by the possibilities of warming the conveyance, a plan ultimately adopted. Furthermore, the same conditions were realized as to the coverings of the individual patient, and the single regulation blanket was replaced by three so arranged as to protect the under surface of the body equally with the upper. The ambulance train was also perfected, especially in the direction of ensuring ease and smoothness in loading and unloading of the patient; and various devices were added to the field stretcher, such as that which allowed a patient with a wound of the chest to be moved and travel in a sitting position, or the subject of a fracture of the thigh or leg to travel throughout with a suspended and extended limb during a period of transport with several transfers from ambulance car to train, and from train to hospital or ship, as the case might be. Of equal, or even greater, importance to the wound itself was the increase in the number of devices calculated to ensure local rest to the injured part of the body. Steady development and frequent revision of these contrivances led to the attainment of a degree of success in this direction which it may fairly be said had never been imagined possible by those responsible for adapting the experience gained in previous campaigns to the provision of means for ensuring rest to the part. In these particulars, therefore, one of the most important adjuncts to wound treatment has undergone an advance which cannot be over-estimated, an advance calculated to diminish shock, to spare pain, and above all to regulate the diffusion of infective material.

It is further of interest to consider what has been the influence of the work of the campaign in increasing other means of limiting and combating the dangers of infection. Early efforts to control the infection of wounds relied mainly on the use of chemical antiseptic applications, and it is noteworthy that these trials were made by men unaccustomed to deal with severe infection of any form, and fundamentally disinclined to employ chemical media, less from an unbelief in their power than from the opinion that powerful antiseptics caused destruction of tissue and were hence inimical to the process of healing. A short experience sufficed to demonstrate the futility of trying to obtain definite primary sterilization of wounds, and further observation threw serious doubts as to the utility of even temporary inhibitory applications.

A still briefer period of trial demonstrated the futility and, often, the positive harmfulness of attempting primary closure

of wounds, even when small or situated in such favourable positions as the face or scalp, with the methods in use at the commencement of the campaign. Even the partial closure of large wounds, with a view to diminishing their eventual size, proved an immediate danger, and was found rather to prolong the period necessary for complete healing than to aid it.

It became abundantly clear that by the time wounds could be definitely dealt with under the existing conditions and arrangements for treating patients, every wound had passed from the stage of a fouled wound into that of a definitely infected one. The treatment of infection then became of an almost purely mechanical nature, the rules for the treatment of open wounds in the forward units, with the single exception of clean, small bullet wounds, being to remove all foreign bodies, and all torn or hopelessly damaged portions of tissue by forceps and scissors ; in the more serious cases to open up the cavity, wash out all recesses, to arrest all hæmorrhage, and to secure efficient drainage by means of tubes. Some tentative suggestions were made as to the use of antiseptic lotions, and gauze dressings—dry for slight wounds, moist for extensive ones—were recommended.

The commencement of the treatment of all wounds, therefore, was by the strictly " open " method, and the only serious attack made upon infection was in the direction of diminishing the amount of infected tissue. In this condition, often after a period of transport amounting to many hours, the wounds arrived at the hospitals on the lines of communication to all intents and purposes heavily infected, although the primary treatment, when efficiently carried out, had more or less localized the extent of the infection in neighbouring parts.

Surgeons working upon the lines of communication, therefore, found themselves in a difficult position. The slighter open wounds caused little trouble and usually healed rapidly with any simple form of moist dressing without further interference. With large wounds, however, and particularly compound fractures, the problem was vastly different. For all practical purposes, the wounds were as septic as if no primary treatment had been undertaken, and although in many cases the provision of effective drainage had prevented any material increase in the area of infection, in others, especially when fractures were present, the movement and disturbance due to transport had resulted in widespread extension to the neighbouring parts. When anaërobic in character, the major portion or even the whole extent of the limb might be implicated.

It was customary to deal with all serious wounds by a second cleansing operation; blood clot and disintegrating tissue were removed, secondary incisions were made if necessary, and the drainage of the wound was rearranged. There can be little doubt that under the conditions that existed at the time these secondary operations were indicated and were the only satisfactory course to take. Yet they had the great disadvantage of exposing new areas of tissue to infection, of inflicting a second strain upon the powers of the patient, and of increasing the period of pain inseparable from the presence of recently infected tissue. The fortunate patients indeed were those who, from the stress of work, comparatively slight injury, or unusual facilities for transport, escaped the primary operation and were dealt with from the beginning on the lines of communications.

At this period the majority of surgeons employed some form of chemical antiseptic in their method of dressing the wounds, or in the fluid employed for constant irrigation or baths, both of which were common procedures at that time. Although, however, individual predilections existed, and many surgeons placed faith in one or other of the lotions employed, it cannot be said that any results stood out prominently from the rest, the best results being obtained by the surgeons who exercised the most care and showed the greatest technical skill and good judgment. The one positive advantage gained from the use of antiseptics, which did not vary throughout the campaign, was the safety ensured by decreasing the liability on the part of the surgeon to carry infection from patient to patient. It was during this period that Wright introduced the physiological method, and although his supporters no doubt exaggerated its attendant advantages, yet its extensive use sufficiently shows that a more or less neutral fluid combined with suitable surgical procedure was, at any rate, of equal value in its local action to antiseptic media. Greater value, perhaps, should be accorded to Wright's thoroughly sound views as to the surgical treatment of the wound, than to the drawing power he claimed for the solution he recommended. It can hardly be doubted that in the early stages of acute infection, the stimulus afforded is greater and more far-reaching in its results and in causing the effusion of lymph than the local application of a hypertonic solution of any nature. One element in Wright's recommendations—that of maintaining infected wounds in a moist condition—is of the

first importance, since only thus can the damming up by dry crusts of the flow of lymph excited by the infection be counteracted. One of the great disappointments of the physiological method, however, was the failure of hypertonic applications to " draw " lymph from the surface of a wound which had assumed a dry condition in association with a general infection of the system. It is of interest to note that in the later stages of the campaign Wright strove rather to encourage the process of phagocytosis, and to maintain the wound as free as practicable from lymph capable of furnishing pabulum for the growth of organisms.

During this stage of the campaign the propriety of closing smaller wounds, which had already acquired a healthy granulating surface after excision of the latter, was considered by surgeons working on the lines of communication, and the practice commenced particularly in the case of gaping scalp wounds. Impetus was given to this movement by a paper by Colonel H. M. W. Gray in which he stated that he commenced this method of treatment on certain lacerated " furrow " wounds in November 1914, and was so impressed by its utility that he had ever since urged that it should be carried out whenever possible. It was not considered necessary to wait until the wound was surgically clean, as the wound if so treated would be healed in a shorter time than it would take to become clean. A large " bank " of inflamed tissue surrounding the wound, " marked pocketing " or the exposure of vascular or nerve trunks or of bone, which it is inadvisable or impossible to remove, constitute the contra-indications to the procedure.

The technique recommended by Gray comprised infiltration anæsthesia, disinfection of the wound surface and parts around it with 5 per cent. to 10 per cent. solution of iodine in alcohol or ether, excision of " the whole wound *en masse*, —skin, flesh, and, if necessary, bone—at a distance of about one-third to half an inch from the raw surface," accurate hæmostasis, washing of the new wound surface with saline solution, and temporary packing with gauze while the surrounding skin was being wiped free of blood or discharge. After substituting fresh towels, fresh instruments, and fresh gloves, the wound was closed with wide sutures which undermined its surface so that no dead spaces were left. In some cases the sutures were introduced in overlapping layers, or a few fine sutures were added to approximate accurately the skin margins. A layer of gauze and mastic (40–50 per cent.) was applied as a dressing.

This method, resembling that in use in civil practice for the secondary closure of operation wounds or for the removal of ulcers, was probably more freely used in 1915 in the Rouen hospitals than elsewhere, although the excision and closure of scalp wounds was often performed at Boulogne. Any wide application to serious wounds was, however, dangerous without the introduction of drainage tubes, and when the latter were used it became a question of diminishing the size of the wound and not of closing it. It follows that only a limited use of the procedure was made, but it is interesting to note that Wright at once grasped the importance of making a mechanical closure of the wound the aim of the surgeon and advocated the measure in connection with the physiological method.

It is convenient here to introduce a short history of the employment of wound drainage, since second to removal of dirt and foreign bodies and the excision of damaged tissue, the provision of drainage formed the most important element in the management of the wound. In spite of the fact that the principle of drainage had been firmly established, yet in the earliest stages of the war, surgeons working in the forward areas were inclined to make inefficient provision for the escape of the abundant discharge which emanates from recently infected tissue, especially in those cases in which they more or less completely closed the wound by suture. This error depended partly on the conditions under which they were working, which did not allow them to follow up the results of their primary measures. It may be, also, that experience in dealing with the large serous cavities in civil surgery—that is with tissue especially capable of dealing satisfactorily with infections of a very definite grade—had somewhat weakened the general belief in the necessity for, and the great efficacy of, free drainage.

The short-lived neglect in this respect was quickly followed by a vigorous reaction. The use of plugs except in the case of uncontrollable hæmorrhage was absolutely condemned; any application which tended to encourage coagulation in the wound and thus obstruct the external opening was banned; and rubber drainage tubes of greatly increased calibre were brought into use. In the first edition of the memorandum on the treatment of injuries in war, tubes of $\frac{1}{2}$ to $\frac{3}{4}$ of an inch in diameter were recommended, and the use of gauze " wicks " forbidden; while later for large wounds plates of perforated zinc suitably shaped were often employed as permanent

retractors to hold large cavities widely open. Meanwhile the disadvantages accruing from these rigid articles, due to the pressure they exercised, the impossibility of avoiding re-infection of the deeper parts of the wound and the difficulty which always existed in determining the proper moment for their removal all militated against their use. Even when continuous or interrupted irrigation of the wound was employed, the tendency of the tube to establish an isolated channel with continuous walls demonstrated afresh another weak point inseparable from this method of drainage, and led to the suggestion of the bandage syphon wicks of Wright, and to numerous attempts to aid local drainage by placing the body or the limb in such a position as to utilize fully the force of gravity in encouraging the exit of discharge.

Then followed a new phase, the first indication of which might be seen in the use of the tablet and gauze pack system, in which it was obvious that the central or deep rubber drain was little more than a symbol, since escape was really first ensured by imbibition on the part of the pack which then sweated generally from its surface, while a second safeguard was ostensibly provided by the obliteration of any nook or cavity in which serum could collect under tension and thence extend into the tissues. Theoretically, at any rate, the pack converted the cavity into an exposed even surface.

The more bold and successful method of complete closure of a septic wound is that adopted by Rutherford Morison, but here again the closure is rather approximation of the wound surfaces and obliteration of its cavity than the establishment of an impermeable barrier to discharge. The surfaces impregnated by B.I.P. were not in a condition to allow of primary union of the tissues, and a permissive cleft remained from which the discharge could and usually did reach the surface. The removal of dressings from a septic wound treated by this method, which did not contain a considerable amount of the typical discharge, was rare. Moreover, the early union was always incomplete and weak, necessitating a longer retention of the supporting sutures than was the case with a clean wound closed in the same manner. It must be allowed that the layers of B.I.P. did really for a time provide a cleft incapable of anything but gradual union, which furnished the opportunity for the escape of discharge. Hence it may be claimed for this method that efficient drainage was provided by means of a thin curtain interposed between the

approximated surfaces, which did not heal until the curtain had been gradually eliminated or permeated and destroyed by vital action on the part of the tissues themselves.

In no method was the principle of wound drainage so thoroughly realized as in the Carrel-Dakin procedure, in which, when properly carried out, not only was it impossible for wound discharges to collect, but those which did form were at once subjected to the action of a chemical medium which rendered them innocuous.

Lastly, the period was reached in which drainage could be dispensed with primarily in consequence of the whole of the infected tissue having been excised, or secondarily when the degree of infection remaining on the surface of the wound could be considered negligible. Thus again the whole cycle of experience on this important principle gained during the last half century was rapidly repeated and reviewed during the progress of the campaign.

Although it is evident that the improvement in the application of mechanical principles led to a steady change for the better in the condition of the wounds generally, and that a small proportion of the wounds were capable of closure after excision *en masse* of the tissues forming their walls, the first further notable advance was attributable to the disciples of the antiseptic method. During the year 1915, the Carrel-Dakin method, while undergoing perfection at Compiègne, began to be extensively used in French and Belgian hospitals. It was to some considerable extent employed in the forward units of the French Army, partly in direct connection with Dr. Carrel's own headquarters, and two competent and enthusiastic supporters were found in Professor Tuffier and Dr. Depage. Many officers of the British service became familiar with the results which were being attained in Paris and at La Panne, and experience tended to strengthen belief in the efficacy of the Carrel-Dakin system.

Professor Tuffier was working on a series of cases in no sense differing in character from those received into the hospitals on the lines of communication, except that some of them arrived in a somewhat later stage of progress. Visits to the hospitals under his charge demonstrated results as good as those seen at Compiègne, and certain notable advances, such as the practicability of rendering sterile and closing old empyema cavities, made a great impression.

Dr. Depage worked under exceptionally favourable conditions. The medical staff at his disposal was highly trained and efficient, and at least twice as strong in numbers as that

possible in any British unit. The patients were brought to the hospital within from four to six hours after receiving their wounds; the definite preparation and dressing of the wounds were carried out by the surgeons under whose control and observation the patients remained until convalescent; and in a unit designed to accommodate some twelve hundred patients there were rarely more than six or seven hundred at any one time. Even taking due note of these advantages, however, it was impossible not to be struck with the general success which was attained, especially in a series of compound fractures. Between June 1916 and January 1917, of 136 compound fractures of different segments of the limbs, 68 were closed by secondary suture with only two failures.

It was this experience which led to the first serious redeparture from the "open method" in its entirety, and the substitution of the procedure of secondary suture. The most important single element in furthering the progress of secondary suture was the institution of Carrel's bacterial count. Although with the increasing confidence bred of success the bacterial standard was at a later period discounted and more or less discarded, the many advantages attributable to it must not be forgotten. It first of all promoted the systematic bacteriological investigation of wounds. This investigation allowed the significance of a rise of temperature to be more exactly appreciated; the discrimination of the various organisms present permitted the formation of a much more exact opinion as to the relative danger of micrococcal and bacillary infections, and of variations in the virulence of varieties of organisms of the same morphological characters; surgeons became familiar with the fact that it was not sufficient to take a drop of discharge casually from any portion of the wound, but that every small recess needed special investigation; and lastly the attainment of the so-called bacteriological standard afforded a confidence in dealing with any particular wound which had formerly been lacking. Further, the discovery was made that secondary union could be attained when the wound still contained numerous bacilli of a certain class, while an apparently negligible quantity of some micrococci made the chances of union hopeless. Moreover, in spite of the assertion by many surgeons that a clinical inspection was sufficient to determine the suitability of a wound for secondary closure provided constitutional symptoms were absent, it remained a fact that the employment of the bacterial standard ensured the largest proportion of successful secondary closures.

The practice of secondary suture after treatment by Carrell's method only became common after the middle of the year 1916, and then confidence steadily increased as to the extent of the applicability of the method. It is interesting to note that in the earlier periods the cases selected included some which at a later date were separated under the heading of " delayed primary suture " by the French surgeons, a classification which was eventually adopted generally. Thus, according to Major J. T. Morrison, " secondary suture may be defined as any suture of a wound not performed within the first twenty-four hours." He lays down that any wound may be closed by secondary suture provided that the skin edges will come together without undue tension, the surrounding skin is healthy, the wound surfaces can be approximated so as to obliterate all dead spaces, and the bacteriological report is favourable. It might be suggested that these provisions strongly resemble those laid down by Colonel H. M. W. Gray in 1915, but, as affecting the eventual wide introduction of the method, it is important to note two outstanding features which account for the success attained at the later period. First of all, the dangerous procedure of mechanical cleansing at this stage in the progress of the wound was eliminated. It was found that even undercutting the skin as an adjuvant to more easy closure of the wound was to be deprecated unless actually necessary, and thus the danger of lighting up latent sepsis was fully recognized and as far as possible avoided. Secondly, the bacterial standard was employed. The results given show a record of complete success in from 75 per cent. to 90 per cent. of the cases dealt with, all of which were serious wounds, and definite closure was obtained in from 12 to 23 days. At this period it had been definitely proved that the advantages of curtailing the actual length of treatment, the elimination of the dangers of an open wound, and the healing of the wound with a minimal amount of scar tissue, were genuine and could readily be attained by the accurate approximation of "surgically" sterile granulating surfaces.

It may be useful to quote here Morrison's description of the technique that was employed in secondary closure, as it was in consonance with that generally adopted.

" (1) *Approximation of the Skin Edges.*—Unless much skin has been destroyed by the original wound, the skin will generally come together fairly easily during the first ten days. Afterwards it becomes increasingly difficult, because cicatrization fixes the edges in their retracted positions. Herniated muscle may also be a cause of trouble, and in such cases it is sometimes possible to unite the fascia over the muscle with catgut sutures as a first step

towards closure. In all cases of difficulty, much may be gained by what the French speak of as 'corsettage.' Strips of strapping are applied to the skin, with a row of hooks stitched along the edge nearest to the wound. The wound edges are then drawn together by means of thin elastic tubing, the wound surface being protected by a reliable antiseptic dressing, which is changed daily. The well-known elasticity of the skin is strikingly revealed, and in two or three days it is frequently possible to close what at first looked like a hopeless gap.

A variation of this method which I have adopted is in some ways, I think, an improvement. Instead of fixing a row of hooks to strapping, I have had them stitched to strips of thin calico some two inches in width. This is then secured to the skin a quarter of an inch from the wound with a spirit glue, in the manner recommended by Page for the attachment of extension tapes. It should be noted that very thorough drying of the skin is an essential preliminary. By this means it is possible to take the pull closer to the margin of the wound, and there is less tendency to inversion of the skin. Then, again, strapping almost always becomes sodden and loosened by lotions or discharges within two or three days, besides offering an excellent nidus for the multiplication of organisms. Both of these disadvantages are obviated by the use of Page's glue.

(2) *Health of Surrounding Skin.*—It is occasionally found that the surrounding skin is abraded, or it may have been irritated by iodine or other applications, or it may be sodden, perhaps even pustular, from unduly wet dressings. It is important that these conditions be set right before secondary suture is undertaken.

(3) *Dead Spaces.*—There is sometimes considerable difficulty in obliterating dead spaces. Pockets should be allowed to fill up, and tunnels to become obliterated, before suture. In the latter case an alternative method, when no important structures are involved, is to slit up the bridge of skin, and then suture. The question of cavities in bone is a difficult one, and is still under consideration. In my earlier cases, it was my practice simply to leave a small drainage tube down to the cavity; and sterilization of bone is often so prolonged a process, that in many instances this is the only possible method of procedure.

(4) *Bacteriological Examination.*—In carrying out the test pathologist and surgeon must work in closest co-operation. The surgeon is best qualified to draw attention to suspicious areas, and he should always be present when the films are being made.

The only exception to the rule, 'before suture, wait till the wound reaches the bacteriological standard,' is possibly the case of the bone injuries already referred to. In such circumstances I have found it safe to suture when the soft parts were ready, even though the bone was still infected, provided that drainage was maintained. Otherwise I make the rule absolute.

Care taken to secure an aseptic result is amply repaid. At first I was greatly troubled by skin infections; stitch abscesses were the rule, not the exception. The reverse is now true. The reason I take to be as follows:—The skin in the neighbourhood of a wound is constantly coming in contact with infected fluids; its pores are full, not only of the usual *Staphylococcus albus*, but also of other and more pathogenic organisms. It is therefore not sufficient in these cases to paint the skin with iodine, the most scrupulous cleansing is necessary, as for instance with spirit soap, followed by ether, and finally by iodine or Harrison's solution, the wound meanwhile being protected by gauze wrung out of antiseptic. The next point on which stress is laid is the picking out from the wound surface of any pieces of cotton or wool that may be adherent. Should silk ligatures have been used, and not have come away, they should now be removed. To shut them up in the body is to court failure.

Where there is any possibility of a dead space being left, or if there is a little difficulty in bringing the skin edges together, a deep mattress suture is inserted. If possible, the needle is carried below a granulating surface,

but in case of need I do not hesitate to pass through it; the latter course is often necessary, as for instance when the floor of the wound touches bone, or lies just over some important structure.

The practice of undercutting is sometimes of great assistance; personally I avoid it whenever I can, but have nevertheless made use of it with advantage occasionally. Of course, the fear of again lighting up sepsis is always lurking in the background.

At first I used silkworm-gut for these sutures. Latterly I have substituted Van Horn's chromicized catgut for all purposes, with satisfactory results. The sutures are passed through short lengths of rubber tubing where they press upon the skin. Buried sutures have not generally been of much help, as they have a great tendency to cut through when tightened.

The next step is to bring the skin edges into accurate and firm apposition. Within the first week this is generally easy. Later it becomes increasingly difficult. Ordinary interrupted sutures are perhaps the most generally satisfactory; but in a few cases I have found a subcuticular suture helpful, especially where the skin has been abraded or softened close to the wound. In certain cases Michel's clips have been all that was required, and small wounds can be closed in this way without any anæsthetic.

A gauze dressing, wrung almost dry out of some antiseptic lotion, is placed on the sutured wound, with plenty of wool, firmly bandaged on. The parts are placed in the position of greatest relaxation, being splinted if necessary; this is a point of great importance.

The wound is looked at daily for the first two or three days; if all goes well, it may then be left for several days. The deep mattress suture is removed after two or three days, the skin-edge sutures about the tenth. I usually take the precaution of keeping the strain off the wound with strapping for another week, when the gap has been of any size. Free movement in such cases is only allowed after three weeks."

It will be observed that at this period the Carrel-Dakin method held the field in the general hospitals, but it is of importance to add that the primary treatment of the wounds was varied in its character and that this circumstance did not materially affect subsequent success.

Another great change in the method of dealing with infected wounds as they arrived from the front on the lines of communication must be emphasized. Except in instances of obvious acute progressive infection, the secondary mechanical treatment of the wounds became much restricted in activity and application. Surgeons generally had begun to appreciate more fully that the local signs of inflammation and the exacerbation of the general symptoms which accompany it were the necessary consequence of the period of transport. Hence wounds of every variety, especially those involving the body cavities and the joints, were given the important advantage of an interval of rest before any active measure was taken in hand. Thus many an operation was avoided; many cases did well which would previously have been unnecessarily and prematurely interfered with, the patients were spared much pain, and the surgeons were spared a good deal of unnecessary work.

The position at the commencement of the year 1917 cannot be better described than by quoting the unanimous conclusions of the Inter-Allied Surgical Conference held in Paris in March of that year.

"(1) It is desirable that the organization of the Medical Service should be so directed as to permit of continuity in the supervision of the treatment of the wounded men.

(2) At the first aid stations and especially in the trenches surgical measures should be restricted to the minimum. They should be limited to dealing with complications which might prove immediately fatal in character, and to the protection of the wounds from repeated contamination. The wound is never to be explored or washed, and should be covered by a dry dressing either sterile or antiseptic in character.

(3) Rapid transport to one of the casualty clearing stations is essential.

(4) It is an advantage if each of these units has one or more advanced sections nearer to the firing line, for the reception of patients seriously wounded (such as those suffering from shock, profuse hæmorrhage, wounds of the chest, abdomen, etc.).

(5) All wounds of war must be considered to be either contaminated or infected.

(6) The object of treatment should be :—

(*a*) To prevent development of infection if the wound is still in the stage of contamination, or to procure sterilization if infection has already developed.

(*b*) To permit of secondary suture, when sterilization is realized.

(7) In the primary treatment of the wound, excision of contused and lacerated tissue and the removal of fragments of clothing or foreign bodies must be considered as the rule except in certain cases where the patient cannot be kept under supervision.

(8) When the wound has thus been properly prepared, primary suture may give good results, especially in the case of wounds of the joints. Primary suture is not to be undertaken unless the wound is only of some hours' standing (at the most eight hours), and only when the surgeon can retain the patient under his own observation for fifteen days.

(9) If primary suture be not undertaken, secondary suture should be performed when the clinical signs indicate that the wound is surgically sterile.

(10) The progress towards sterilization should be systematically controlled by a series of bacteriological examinations, and a "curve" should be constructed to allow the degree of sterility to be determined.

(11) When patients have to be hurriedly evacuated, and definite preparation of the wound postponed, a dressing, the action of which should continue during the period of transport, may be usefully applied. Further researches on this subject are needed.

(12) Several methods for the progressive sterilization of wounds are available, which allow of the routine practice of secondary suture."

Consideration of these conclusions, while it affords evidence of progress, also indicates that opinions had by no means crystallized on many points. The most important conclusion is that referring to primary suture. It is interesting, however, to note the caution with which the practice of primary suture was introduced, and the limitation of its adoption. In fact, the procedure was at that time being somewhat more widely practised, especially in the case of large wounds in the region of the shoulder and the head. The second striking feature is the

restraint exhibited in recommending any one method of chemical sterilization of the wound, although the successful application of secondary suture as a common procedure was certainly a consequence of the introduction of the Carrel-Dakin system. Lastly, the question of the treatment of wounds during transport was still regarded as far from any satisfactory conclusion. From this period onward, progress was steady and rapid, the treatment of infected wounds met with behind the front lines had been placed on a firm and intelligible basis, while the success attained in the treatment of wounds of the joints was extended to the majority of all wounds, even to the closure of the compound fracture.

The question of the primary closure of wounds is dealt with elsewhere. The results attained were such as to satisfy the most exacting critics in the hospitals on the lines of communication and sympathetic colleagues at home.

Only one new procedure now called for adoption on the lines of communication, namely, the so-called "delayed primary suture." The majority of these cases comprised the class of wounds in which doubt existed as to the safety of primary closure, and which were left for twenty-four to forty-eight hours in order to be certain that constitutional signs indicative of infection did not develop. They were usually dealt with at the casualty clearing stations, but in times of stress they were sent down the line. In such cases experience already gained in the practice of secondary suture was of great value, and they were closed most successfully after a somewhat longer interval than would have been the case if they had not been subjected to transport. The strict classification of cases under this title was not maintained, and in principle it is difficult to establish a definite limit between them and those classed as secondary sutures. Neither a time limit, nor one founded on the stage of development reached by granulations, two methods open to criticism, was found satisfactory, for pathologically all such wounds are the subject of a certain degree of infection, and it was the nature and grade of this, which determined the suitability for closure or for further treatment respectively.

Great as the advance eventually made may be considered, and although an actual approach to the ideal had been made, yet it must be remembered that the casualty clearing stations and the advanced operating units had been developed to a degree unknown in any former campaign, and that the work was performed under a condition of fixity of tenure not capable

of realization in any war in which extended military movements are taking place. Furthermore, only a limited percentage of the wounds proved themselves suitable for primary closure, and owing either to delay in the commencement of treatment, to the severity and extent of tissue damage, to the obstacles presented by exposure and fouling of important structures, such as great vessels or large nerve trunks on the surface, or to the situation of the injury, as for instance in the perineum, it was necessary to reserve a large number for delayed primary or secondary suture. In the primary treatment of wounds, it was abundantly shown that if the surgical or mechanical treatment had been sufficient, it was practically immaterial what form of antiseptic was employed, or whether the wound was dressed with a solution of soap or simple sterile gauze. The mechanical ablation of the contaminated or infected tissue was the single effective factor. The question of the infected wound was more complicated ; in the first place, except in the case of wounds of limited extent and simple conformation, mechanical sterilization was difficult or impracticable, and if it failed to effect its object it was open to grave risks and objections. Hence it was generally recognized that a procedure of progressive sterilization was the only practicable resort. Here, odd anomalies of opinion were discovered. Some of the advocates of primary sterilization by powerful chemical media, or the use of similar substances to act as inhibitory agents, decried the repeated or continuous application of less powerful means of the same nature. Other surgeons used continuous applications of antiseptics combined with mechanical treatment on recognized surgical principles. A third school decried the use of antiseptics in any form, either attempting to strengthen the various factors in the process of healing, or to trust to the powers of nature after the surgeon had placed the wound under the best conditions for healing.

Of these various schools it is indubitable that the supporters of antiseptics gained the initial success, but it was by the odd paradox that the success of the antiseptics depended on the skill with which the surgical means forming a part of the system were perfected and carried out. Even enthusiastic supporters of the antiseptic system discovered that in a wound treated by exposure to the sun the same mathematical estimate of the length of time necessary for its closure could be made as with the Carrel-Dakin system, and that the period necessary was practically the same in both cases.

Can it then be concluded that the era of the employment of antiseptic media has closed in military surgery? Although firm belief is still held in what are so unfortunately misnamed "aseptic methods," the use of antiseptic media will certainly continue. The problem of treating infected wounds is to prevent re-infection. In the vast majority of cases, prolonged suppuration depends on the repeated infection of a wound which has time after time struggled to free itself of the invading organisms by vital action on the part of the tissues. The local application of an efficient antiseptic, although not theoretically necessary, is the most powerful means at the disposal of the surgeon, to compensate for errors in procedure on his part which haste and the often unavoidable surroundings rendered practically inevitable. Few of the strongest supporters of the pure "aseptic" system have the courage to discard the precaution of disinfecting the skin surrounding the wound with alcohol, iodine, picric acid, or some such agent. How much more advisable must such a procedure be in dealing with the gunshot wound under the conditions of active service? Again, how often under these conditions may not the surgeon like to make sure of his "sterilized aseptic gauze" by soaking it in an antiseptic solution? Who can deny the convenience and efficiency of the use of antiseptic solutions for washing the gloves, and often for dipping the instruments in, when passing from patient to patient in a crowded ward? Lastly, with regard to the wound itself, it is true that no observer has ever been able to show that any antiseptic can sterilize infected living tissue, but no doubt can exist as to the power of many antiseptics to inhibit, if not to destroy, the power of growth of many organisms in the wound discharge. In fact, even a certain specific action of different antiseptics on organisms of separate classes has been shown. On all these grounds the use of antiseptic media is advisable.

Many are the coadjutors to whom such success as has been attained must be attributed, but the unprejudiced observer must allow that surgery is most of all indebted to two combatants in opposite camps. To Wright must be assigned the credit of familiarizing every student with the intimate process of healing to a degree uncommon before the war, and of emphasizing the reliance which the surgeon may properly place on the power of the natural process. The reader of Wright's papers also cannot fail to gain advantage from observing the gradual and progressive manner in which true surgical principles and their application developed in the mind of a

scientific investigator and, further, the ingenious methods by which he attempted to realize and render practical the principles he propounded. To Carrel is due the triumph of building up a system of treatment founded on a belief in the power of antiseptics, and rendered a success by the perfection of the technique which he developed in the surgical treatment of the wound. A small band of sturdy supporters of the "aseptic system," of whom Cuthbert Wallace was the leader, maintained, however, an unwavering belief in the truth of the principles they professed, in spite of the stress and turmoil of the struggle.

It may probably be asked by the superficial observer in days to come, was this then the only result of the strenuous efforts and investigations of a whole army of pathologists and surgeons, exerted for a continuous period of four years with an illimitable amount of material at its disposition, a return to the fundamental edict of Hunter that "the injury done has in all cases a tendency to produce the disposition and the means of cure. The stimulus of imperfection taking place immediately calls forth the action of restoration." The surgeon of the future even if he thoroughly believes in the principles enounced has not, however, an easy task before him in attainment of the ideal of "primary closure." The mechanical elimination of the infection-bearing tissue in a gunshot injury, needs experience and meticulous precaution far beyond that required to ensure success in many of the greatest operations of surgery in civil practice. The surgeons who attained the results above chronicled obtained their efficiency as a result of long and painfully acquired experience. They struggled in a field of unexampled difficulty and under conditions calculated to daunt and depress even the most enthusiastic. They built up their system by painful steps with honest and constant effort, and to them is due a meed of praise not inferior to that which has been accorded to the greatest men of the past.

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CHAPTER XIII.

SURGICAL WORK IN PALESTINE, MESOPOTAMIA AND MACEDONIA.

THE campaigns in Palestine and in Mesopotamia presented some special features with regard to surgical work and the following notes bring out the experience of surgeons in these theatres of war. The amount of surgical work can in no way be compared with that on the western front, but in the case of Palestine the experience was that of mobile warfare, and in Mesopotamia that of a prolonged siege, as well as of surgical work in a climate with an extremely high temperature. The surgery of the Macedonian theatre of war was complicated with malaria, and in all these campaigns complications arose from the special difficulties of transport.

Palestine.

The fighting that occurred during the crossing of the Sinai Desert was confined almost entirely to the mounted troops, the four principal engagements being the battles of Romani, Magdaba, Rafa and Gaza. In all of these the surgical staff, the majority of whom had gained experience in treating wounds either on the Gallipoli Peninsula, or in France, were agreeably surprised at the remarkable absence of gas gangrene. It was generally conceded that this was not due to any alterations in the form of treatment the wounded received, but to the nature of the soil of the country in which they were fighting. The nature and behaviour of the wounds corresponded closely with what was seen during the South African campaign.

During the later stages of the crossing of the desert, many of the British troops, more especially the cavalry, developed sores on their hands and arms, and occasionally on their lower limbs. These were described as desert sores. They appeared first of all as small subcuticular swellings like minute blisters, which subsequently broke down, leaving a superficial ulcer which was most intractable to heal, and they were in appearance similar to the veld sores from which the troops suffered during the South African war. Craig found the infecting organism in many of these cases to be a diphtheroid germ, and in confirmation of this certain cases improved very much under the administration of antidiphtheritic serum.

The official enquiry that was conducted into this disease revealed many points of interest. It was found that troops that had been stationed longest on the desert suffered most, but Indian troops were immune to the disease. Many varieties of local applications were used, none of which had pre-eminent value. Certain observers considered the nature of the diet a contributing factor and the scanty water supply was considered by most to be a contributing cause, a bath in fresh water being unobtainable. When troops were stationed on the seashore they rapidly improved in health in this respect. It was also noticed that the sufferers from this ailment who went home on leave or were invalided recovered quickly on the voyage.

During the crossing of the desert no special arrangements were made for additional surgical assistance in the advanced areas, nor at first was there any great need for this. The majority of the medical officers of the field ambulances belonged to their original territorial force divisions and many of them were hospital surgeons in civil life. For example, in one mounted brigade field ambulance, four of its six medical officers were on the consulting staff of teaching hospitals.

The necessity, however, for special arrangements for the provision of surgical assistance was evident at the first battle of Gaza, which was fought on 25th March 1917. Colonel Wade of the Scottish Horse Mounted Brigade Field Ambulance, was consequently directed by the D.M.S., Surgeon-General Maher, to report as consulting surgeon to the D.D.M.S. in the field. He assisted the staffs of Nos. 54 and 53 Casualty Clearing Stations, and further assistance was obtained from the 52nd (Lowland) Division, in which there were several surgical specialists and two officers who specialized in anæsthetics in civil life.

In dealing with the wounded from this battle, one feature was noteworthy as regards their accommodation. The advanced casualty clearing station possessed accommodation for 400 patients only. The numbers received were much in excess of this and many cases were consequently left on their stretchers in the open, an ample supply of blankets being available for them. It was observed that these patients were more comfortable and slept better in the open air than those accommodated under canvas.

The second battle of Gaza was fought on 19th April 1917, prior to which several surgeons were sent to assist the staff of the front line casualty clearing station. These surgeons were

mainly medical officers temporarily quartered in Alexandria during their passage home to England from Mesopotamia. As on the previous occasion, however, no arrangements had been made for providing them with equipment to render them independent of the casualty clearing stations to which they were attached.

An advanced operating unit, as it ultimately developed with the Palestine Force, may be said to have originated from a request for special surgical assistance by the D.D.M.S. of the Desert Mounted Corps. During the period after the second battle of Gaza, when the troops were holding a line on the borders of Palestine, long distance reconnaissances were frequently made by the mounted troops. On several occasions it was realized that valuable time was lost in bringing back the severely wounded to the nearest medical unit equipped for performing major surgical operations. To deal with such cases an Australian mobile advanced operating unit was formed and to it was attached a surgical operating car, which had been designed by Colonel Wade for the Scottish Horse Mounted Brigade Field Ambulance, and had been completed in December 1914. This car was used at Suvla on the Gallipoli Peninsula, and later on in the desert near Kantara. It contained all the equipment necessary for performing major surgical operations within ten minutes of the arrival of the car at its destination.

This Australian advanced operating unit was commanded by Colonel Story and had a permanent staff which did not belong to any other medical unit. This arrangement, however, proved too wasteful of medical personnel, owing to their not being continuously employed and it was not adopted in connection with the advanced operating units which were subsequently formed.

The first occasion on which the Desert Mounted Corps Mobile Operating Unit was employed in a general engagement during mobile warfare was at the capture of Beersheba, in November 1917. On that occasion the unit accompanied the cavalry and entered the town within a few hours of its capture. A considerable number of seriously wounded patients had already accumulated there, and these were accommodated in a large building which was hurriedly improvized for their reception.

The surgical car that formed part of the equipment of the operating unit was drawn up adjacent to the window of the room that was improvized as the emergency operating theatre. The necessary sterile warm and cold lotions were already prepared ready for use and the electric cables from the storage

batteries of the C.A.V. lighting set on the car were laid into the room and an electric light supplied from this source was suspended over the operating table. For several days this theatre was used continuously for operating on abdominal cases and other seriously wounded. The car outside was used as a sterilizing and preparing room for the theatre and from it was also obtained a constant supply of electric light which rendered operating much easier and safer for the surgeon and patient alike.

When the cavalry followed the Turks who were retreating across the maritime plain, the operating unit accompanied them and did useful service in several places, until finally it was quartered in the Monastery at Ramleh, from which position it later moved on to Jerusalem.

The surgical experiences gained during these operations confirmed the opinion formed of the value of a unit, consisting of several surgeons experienced in the performance of major surgical operations, being immediately available for the treatment of serious cases. It also demonstrated the fact that the equipment required for the performance of such operations was not necessarily either bulky or elaborate, and that a unit of operating surgeons could co-operate advantageously with the various field ambulances to whose personnel they were attached and whose patients they were treating. The officers commanding the field ambulances were responsible for providing the necessary accommodation and care of the wounded and they welcomed the arrangement by which they were relieved of the onerous and tedious responsibilities of carrying out the surgical treatment of those patients who required serious and prolonged operative treatment.

The disadvantages of the equipment that the unit possessed were also demonstrated. Thus, it was shown that the surgical car, although ideal in its design and well mounted on a new Wolseley chassis, was not easily transported through the difficult and almost roadless country in which the fighting took place. For such country the Ford car was found to be much more serviceable.

When, therefore, Major-General Swan, who had a wide experience of the medical arrangements on the western front, became D.M.S. of the Egyptian Expeditionary Force, approval was given for the formation of several other mobile operating units, with a view to giving effect to the principle of conveying the operating surgeon close to the firing line wherever possible, so as to treat the wounded at the earliest possible moment.

Owing to the length of the line of communication to the base and the fact that most of the hospitals in Egypt were amply staffed, surgeons could be temporarily spared from them for employment with the troops during active military operations, and instructions were given for the creation of various operating units to come up from Alexandria, Cairo, Kantara and Bellah. In the formation of these units no hospital was unduly depleted of its surgical staff, and instructions were issued that where such personnel was temporarily withdrawn from a hospital other medical officers, not necessarily trained in special surgical work, should immediately replace them. The personnel authorized for a surgical unit was one senior surgeon, one junior surgeon, an anæsthetist and four orderlies, of whom two had been trained as aseptic theatre attendants, and a third in the duties of a septic theatre orderly, while the fourth acted as general duty orderly in and about the theatre.

The transport of each unit was four box Ford cars, each capable of carrying 5 cwt. of equipment through any country. The equipment transported was so arranged that no package weighed more than 150 lbs., so that it could be carried forward on camel back, if this proved to be necessary, the authorized load for the male camel being 300 lbs.

Each unit was assembled on the understanding that it would be working in conjunction with a field ambulance. The box Ford cars when not in use were placed under the charge of the officer commanding No. 35 Motor Ambulance Convoy. He was responsible for their care and for transporting the unit to any destination to which it was directed to proceed, and also for providing drivers for the cars.

In Palestine the three military operations during which the advanced operating units were employed, were the raid on Ammam, the fighting north of Rhantieh and the Es Salt operations. During the first the advanced operating units were situated at the 20th Corps Main Dressing Station at Jericho, during the second at the 21st Corps Main Dressing Station south of Medjal Aba, and during the third at the Desert Mounted Corps Main Dressing Station at Jericho.

During the Es Salt operations the Anzac field laboratory, the Anzac dental officers and three officers from the field malarial units, were attached to the corps main dressing station. This arrangement proved a great success, as, their customary work being in abeyance, they gave anæsthetics, dressed minor cases, gave anti-tetanus injections, conducted post-mortem examinations and proved extremely useful in many other ways.

The original instructions given by the officer commanding the Corps Main Dressing Station were to transfer all serious cases to the advanced operating unit section. This proved difficult to carry out and unsatisfactory. Orders were therefore issued to transfer only penetrating gunshot wounds of cranium or chest, all abdominal or buttock wounds, fractures of femur, cases of serious hæmorrhage, collapse, or with tourniquets applied, and any other serious cases, according to the discretion of the medical officer. All cases before transfer to the operating unit section received anti-tetanic serum. This was found to lead to a much more satisfactory filtration and expedited the work of the general reception tent.

On arrival at the operating unit section of the main dressing station, all wounded were admitted to a reception tent where they remained until disposed of. All cases requiring operation were kept there until taken to the theatre, except head cases or patients suffering too profoundly from shock to stand operation. Head cases were transferred to the head tent, where a special orderly, trained in the use of hair clippers and a razor, prepared the case for operation. He covered the wound with an antiseptic swab, clipped the entire scalp close and shaved at least one-half of the head. The majority of chest cases were transferred to the chest ward after examination, but a small minority of open chest wounds underwent operative treatment and were closed with very satisfactory results. Great improvement in the seriously wounded chest cases was found to be brought about by rest in bed in the sitting position.

Abdominal cases were examined immediately on admission and laparotomy was performed if there were signs of internal hæmorrhage or undoubted penetration of the abdominal cavity in the danger zone, or if the patient were not unduly collapsed and had a pulse of under 120 per minute. The cases that presented most difficulty were those in which penetration was uncertain, contusion peritonitis simulating perforation was present, or penetration through the "safe" zone had occurred. These were treated by being placed in the Fowler position with instillation of rectal saline. A half-hourly pulse record was kept. All so treated recovered, a brilliant result in view of the risk of an exploratory laparotomy in the circumstances.

All cases of pelvic wounds, buttock wounds and wounds of the perineum, were examined under an anæsthetic immediately

on admission. All wounds of the bladder were treated by supra-pubic cystotomy, and all wounds of the rectum by free drainage of the pelvis.

Wounds of blood vessels in several cases were treated because of primary hæmorrhage, large hæmatoma and pressure gangrene.

Fractured jaws were treated for three days by hourly eusol irrigation until the risk of septic pneumonia had passed. All other fractures were suitably splinted.

Uninfected, punctiform, penetrating wounds of the knee joints were splinted and no operation performed. If the joint was infected or the wound large, or if the bone was much comminuted, it was excised, cleansed, disinfected and closed.

Primary excision of wounds was practised in cases of large flesh wounds, wounds complicated by serious hæmorrhage or lodgment of infected foreign bodies. Several primary unions followed this line of treatment. All serious flesh wounds were suitably splinted.

Amputations were performed for incurable laceration of limbs, gas gangrene and pressure gangrene.

The routine procedure for wound disinfection employed in large wounds was excision of all damaged tissue, disinfection with spirit, application of B.I.P. and closure of wound, where complete obliteration of the cavity was possible; packing with gauze smeared with B.I.P. when this was impossible. The results obtained by this method of treatment were very satisfactory. Experience confirmed the advisability of using the minimum amount of B.I.P., owing to its toxicity in recent flesh wounds.

The routine treatment of wounds actually infected with gas-producing or other organisms was free excision, the wound being left open and irrigated every two hours with two pints of eusol.

The results of the cases operated upon are summarized in the Tables I and II.

In one of the fatal cases of pelvic injury in Table I it was considered that the bullet had just missed penetrating the pelvis. At the post-mortem examination, however, it was found to have glanced across the outer wall and torn the small intestine. Laparotomy had thus been omitted.

In the spine case in Table I, the operation was for a large wound exposing the spinal cord. The patient lived three days and at the post-mortem examination the wound was septic. Possibly a certain degree of iodoform poisoning contributed to the fatal result, emphasizing the importance in a recent wound of using only a very small amount of B.I.P.

Table I.—*Ammam Operations.*

Nature of Injury.	No. of cases operated on	Deaths.	Cause of Death.
Abdominal (penetrating)	5	1	Hæmorrhage.
,, (non-penetrating) ..	2	—	
Pelvis	6	3	Shock. Pelvic cellulitis. Peritonitis.
Head	11	2	Shock.
Chest	10	1	Shock.
Spine	1	1	Acute sepsis.
Fractured femur	9	—	
,, tibia and fibula	8	—	
,, humerus (one case of bilateral fracture)	7	—	
,, lower jaw	2	—	
Joints (penetrating wounds) knee ..	4	—	
,, ,, ,, wrist ..	2	—	
Amputations, upper limb	3	1	Acute sepsis.
,, lower limb (one case of amputation of both limbs)	4	—	
Ligature of vessels (axillary, brachial, femoral)	3	—	
Comminution of clavicle and pneumothorax.	1	—	
Large flesh wounds	18	1	Shock.
Total	96*	10	

* 36 were multiple wounds.

Table II.—*Es Salt Operations.*

Nature of Injury.	No. of Cases operated on	No. of Deaths.	Cause of Death.
Abdominal	8	4	Peritonitis, hæmorrhage.
Pelvis	7	2	Pelvic cellulitis, peritonitis.
Head	9	3	Encephalitis, shock.
Chest	8	—	
Spine	4	2	Acute myelitis, spinal meningitis.
Fractured femur	9	1	Shock.
,, tibia and fibula	3	—	
,, humerus	2	—	
,, lower jaw	2	—	
Joints (penetrating wounds), knee ..	8	—	
,, ,, ,, ankle	1	—	
,, ,, ,, elbow	2	—	
Amputations, upper limb	2	—	
,, lower limb	4	1	Iodoform poisoning.
Ligature of vessels (common, superficial and deep femoral veins).	1	—	
Large multiple flesh wounds ..	11	2	Gas gangrene, shock and infection.
Total	81	15	

In the fatal case of iodoform poisoning the patient underwent amputation of the lower limb. The wound remained aseptic. The clinical indications suggested iodoform poisoning. Blood cultures and wound cultures were negative. Post-mortem examination revealed no infection. It is probable that the use of B.I.P. in a large raw wound contributed to his death.

Examination of the wounded in the various hospitals on the lines of communication confirmed the benefit of the preliminary filtration they had undergone in the advanced operating units. It emphasized at the same time the importance of giving detailed information on a patient's transfer card at every unit through which he passed.

In reviewing these results it is apparent that as compared with the military operations in France the number of wounded that had to be dealt with was trivial. The value of the information, however, appears to be considerable as the military operations were closely akin to the usual type of campaign in which the British army was engaged on distant frontiers, where mobile warfare was carried on in a country badly provided with roads.

On the occasions when advanced operating units were employed, they were always commanded by a surgeon who had in an earlier stage of the war served as a regimental medical officer or in a field ambulance. The advantage of this was found to be very great. First of all, he was familiar with life in the field. He knew how to care for his men and meet any sudden difficulty that might arise during their transport, such as obtaining rations for them. When he arrived at the unit to which he was attached, he co-operated much better with its work, appreciating the difficulties, realizing the limited nature of the services he could render and the limited facilities that could of necessity be afforded him.

During the final advance to Aleppo, seven operating units were employed. The value of these can be best appreciated when it is mentioned that in the final stages of the campaign the troops were operating several hundred miles from railhead and that at the capture of Damascus an advanced operating unit entered the town the same afternoon. It proceeded to the French Hospital and the Edinburgh Medical Mission Hospital in that city, and forthwith commenced work.

The scheme of establishing operating centres at the corps main dressing stations undoubtedly led to the saving of life, and to a speedier and more successful cure of the wounded.

The further development of the facilities for operative treat-

ment provided by the advanced operating units was amply justified by the results obtained. The points brought out in the experience of the consulting surgeon were that the list of operating unit teams should be frequently revised, and that at least one unit should be in waiting and immediately available from the lines of communication when required, being warned to be ready to move at short notice ; also that a memorandum of instructions should be drawn up and issued to the commanding officers and members of the advanced operating units and others concerned before they proceeded to the front area, describing the nature of the work they would be called upon to perform, the equipment they would possess, and how best to assemble the same ; and further, that equipment similar to that of the advanced operating unit should be available for use at a corps main dressing station.

Mesopotamia.

One of the features connected with surgical work in Mesopotamia was the fact that the wounded had to be transported for long distances in a country which possessed neither good roads nor railways and where the river was the most available method of transport although it was not easy to navigate and in the early days the supply of ships was limited. Roads where they existed were liable in winter and after rain to be converted into thick, tenacious mud, and in summer they were many inches deep in dust. Moreover, the surface was often very uneven and large depressions or irregularities were not infrequent. They were improved during 1917 and 1918, and by the spring of the latter year it was possible to move wounded comfortably in motor ambulance cars.

Broad and narrow gauge railways were also constructed, and on the former well organized and equipped ambulance trains were employed. Ambulance trolleys on light railways also proved a suitable means of transporting wounded from outlying casualty clearing stations to railheads or to points on good roads where motor ambulance cars could come up.

In the latter part of 1916 and first half of 1917, the majority of the sick and wounded were brought by river to Sheikh Saad where there were several casualty clearing stations and hospitals on the right bank of the Tigris. It was thus possible to transfer the patients from the boats to the hospitals with a minimum of land transport. Various types of boats were used for this purpose, including hospital ships fitted with operating theatres and smaller boats such as paddle steamers. Wounded were

sent down in these when they were able to be moved to the hospitals of Amara and Basra. Still later in 1917 and 1918, several new hospital ships fitted with every modern convenience were in use. On the Euphrates and upper part of the Tigris, it was not possible to use these hospital ships, and only smaller boats such as motor launches could be employed.

The warfare in Mesopotamia differed materially from warfare on the western front in that after the capture of Kut in February, 1917, it became very largely one of movement, and thus the fighting line was frequently far away from the casualty clearing stations and stationary hospitals. The former were moved up as the army advanced, so as to be near the scene of action, but the fact that the army moved on and therefore reached places where transport became increasingly difficult, had the important result of rendering it extremely difficult to get the abdominal cases back early to the casualty clearing station. Various schemes and plans were discussed to deal with this, but none of them were applicable to the natural conditions of the country.

The hospitals in the large towns, Basra, Amara and Baghdad, were in buildings specially selected and suitably fitted up for surgical work, and in every respect as complete and well equipped as in any other of the war areas, the chief difficulty in connection with them being the long distances over which patients had to be transported before they reached the hospitals; also, wounded had to be transferred as soon as possible to India. The most seriously wounded were kept in stationary hospitals until convalescence was established, but sooner or later touch was lost with practically all of them and thus it was very difficult to ascertain any final results, with the exception of those who died in hospital. This was specially the case with regard to head injuries and injuries of nerves and blood-vessels. As regards nerve injuries, only a few cases could be operated on, at any rate in the Baghdad area. The patients were usually sent down before the primary wound had healed and was free from sepsis, and until these conditions were established it was inadvisable to attempt nerve suture.

In some hospitals, fractures, particularly of the femur, were placed in one ward under the care of the surgical specialist. The various means of treatment were used, such as Thomas' thigh splints, Balkan frames and Sinclair's splint. The wounds were irrigated either continuously or intermittently with the different solutions so widely recommended. The conclusion come to was that it was not so much the particular

method which was the most important factor, but the care and assiduity with which the details of the treatment were carried out. Again, the necessity of transporting cases from the forward areas to places lower down the river, and from Basra to India, was bad for the patients. It not infrequently happened that cases of fractures which in Baghdad appeared to be doing well and had to be sent down, were not in a satisfactory state when they arrived at Amara, Basra, or in India.

Many cases of extensive lacerated wounds were seen, but the number and severity do not compare with those in France. This was largely due to the fact that continual shelling of trenches with high explosives was not a frequent occurrence in the campaign. There were very few extensively lacerated wounds of the chest and most of the lung injuries were due to bullets. Hæmothorax was frequent and usually the patients did well after aspiration of the chest. The absence of high explosive shelling accounts largely for the absence of the severe degrees of shock which were seen in France. But climatic conditions were unquestionably a factor which limited the onset of such shock. When it was very cold in winter, the cold was dry; when there was rain, there was no extreme degree of cold. Hence, men were rarely exposed to the combined effects of severe cold and wet, nor were they left out for any length of time after being wounded. Transfusion of blood was not practised; warmth, hot drinks, saline injections, rest and sleep served to restore the man. In some cases gum acacia solution was injected, but the number was too few and the results not sufficiently uniform to determine whether it was superior to simple saline solution or not.

From the nature of the country, the wounds were not heavily soiled with earth, manure or other septic matter. Prophylactic injections of tetanus anti-toxin were given as a routine. Only one case of tetanus was seen in a British soldier by Colonel Legg, the consulting surgeon, and it was doubtful if a prophylactic dose had been given in this case. But among Turkish prisoners there were several cases. Major Barber records thirty cases amongst British and Indian troops during the siege of Kut, of whom only four recovered. Suppuration in the wounds could generally be controlled by excision of all damaged tissues, free drainage and irrigation. Only a few cases of gangrene occurred. One case occurred in a wounded Indian, who had a traumatic aneurysm of the left femoral artery in Scarpa's triangle. As the aneurysm continued to increase in

size, ligature of the external iliac artery was carried out just above Poupart's ligament. The man had been in hospital for some days and his original wounds were healed; but forty-eight hours after the operation, gangrene rapidly supervened and he died in a short time.

Perinephric abscesses were not uncommon. These were usually unilateral, but one case under the care of Major Cope, in No. 31 British General Hospital at Baghdad, had an abscess around each kidney. These abscesses usually followed boils or some similar infection, and the organism commonly present was the *Staphylococcus aureus*. Pyæmia after septic infections occurred; the virulence of the organism was noteworthy. Parotid abscess was not infrequent. Some of the patients lost the whole of the parotid from sloughing; it might be bilateral and in every case the patient was severely ill.

Dysentery caused difficulties in diagnosis by simulating appendicitis and leading to the formation of large masses of matted intestine and omentum, and to pericolic cellulitis with occasionally abscess on the right side of the abdomen.

With regard to high atmospheric temperatures in Mesopotamia, much prominence has been given to the dangers of operating in extreme heat. All the consulting surgeons note that they operated during the height of the hot weather on all types of cases and never had occasion to regret having done so. In their opinion great heat never had any effect on the patient at the time of the operation, nor did it tend to increase the liability to sepsis afterwards. The only instance of heat effects which came under Colonel Davies-Colley's notice was a slight non-fatal heat-stroke following an operation for hæmorrhoids. In this case the patient was placed, immediately after the operation, beneath an overhead electric fan which directed upon him a blast of hot air from the roof of the hut in which he lay. The hut was of the type used extensively as wards in Mesopotamia. The roof was not thick enough and moreover was perforated for ventilation, so that the fans sucked in the intensely heated air from the outside of the roof and drove it down on the heads of the patients. In such huts the upright movable fan was much preferable; it was only in the solid buildings with thick mud roofs and no roof ventilation that overhead fans were safe and more convenient than the others during high atmospheric temperatures.

With regard to antiseptics in the treatment of suppurating wounds, Colonel Davies-Colley notes that eusol and B.I.P.

stood out as eminently useful, the latter especially so for patients who had to be transported over a long distance with infrequent changes of dressings.

Some interesting points connected with surgery during the siege of Kut have been recorded by Major C. H. Barber, I.M.S., more especially with regard to penetrating wounds of the abdomen. Between 5th December 1915 and 29th April 1916, 2,418 wounded were brought into the hospitals during the siege, and of these 488 died, 1,680 were returned to duty, and 250 were still in hospital when Kut fell. The results of operation on head cases were disappointing, but cases with penetrating and perforating wounds of the chest did well as a rule.

With regard to penetrating wounds of the abdomen, Major Barber describes a series of 76 cases during the siege, in 40 of which abdominal sections were performed. The general conclusions drawn from his experience were that hæmorrhage was the most serious symptom, that slight symptoms or small wounds did not justify the assumption that the intestinal lesion was also slight, and that operative interference should be carried out within twelve hours after the infliction of the wound, if successful results were to be expected.

Altogether some 200 major operations were performed during the siege. The supply of chloroform was ample, and for the greater part of the time there was a good supply of surgical dressings. Amongst the major operations performed were 32 craniotomies, 40 abdominal sections, 36 amputations, and six ligatures for aneurysm. The results of craniotomy were dis-disappointing, but amputations did well. As the food supply diminished, it was found that conservative treatment of limbs became less and less possible.

Scurvy amongst the Indian troops and beri-beri amongst the British delayed the healing of wounds ; in fact, in many cases, in which scurvy developed, healing ceased altogether, a condition which was observed also amongst the Russian wounded in the Russo-Japanese War during the siege of Port Arthur.

There were also some interesting facts noted in connection with the healing of wounds in different races during the siege ; for example, wounds healed more frequently by first intention and more quickly amongst the Gurkhas than amongst others. They ate horseflesh as soon as it became necessary, and did not suffer from scurvy. Wounds amongst Sikhs, Pathans and Punjab Mussulmans, healed well as a rule and were not much affected by scurvy, but amongst the Mahrattas the recuperative

power was very low. The Arabs and some of the civil population of Kut appear to have recovered from extensive injuries both of the head and abdomen which, amongst other classes of men, would probably have proved fatal, and this class of patient also suffered little from shock after major surgical operation.

Lieutenant-Colonel E. V. Hugo, I.M.S., notes special features connected with surgical work during the advance from Baghdad.

In October 1918, during the advance to Mosul, the advanced combined casualty clearing station was situated some 15 miles from the railhead at Tekrit, at an isolated spot on the upper reaches of the Tigris.

The so-called road between the advanced casualty clearing station and railhead at Tekrit was so rough that it was deemed necessary to send down the seriously wounded and fracture cases by river on rafts made of inflated skins and frames of poplar poles, the state of the river being such that launches could not be used. On such rafts, which were in constant use on the Tigris between Mosul and Baghdad in the days before the war, the wounded were conveyed comfortably to the casualty clearing station at the railhead at Tekrit and thence were conveyed in comfortable and up-to-date broad gauge ambulance trains to Baghdad.

Lieutenant-Colonel Hugo's experience as consulting surgeon in the advance was that nearly all head wounds ended fatally, although retained as long as possible in the advanced casualty clearing station. Probably the long distances and rough roads which the ambulances had to travel before reaching the casualty clearing station prejudiced their chances of recovery.

As to abdominal wounds, few cases found their way into the advanced casualty clearing station, and those who survived the journey from the front were in such a condition that operation was out of the question. To guarantee any successes, the cases had to be seen and operated upon early, and the nature of the country and movements of the army rendered this impossible.

Macedonia.

The following notes on the surgical work in Macedonia are taken from a report by Colonels Sir Crisp English and R. E. Kelly, R.A.M.C., the consulting surgeons of the Macedonian Expeditionary Force.*

The special condition in Macedonia that differed from those

* *British Medical Journal*, 16th March 1918.

in other areas of operation was that most of the seriously wounded had to be transported by mule travois or mule litters and this added greatly to the delay in bringing men wounded in the chest or abdomen to the operating centres. The travois worked satisfactorily on the whole, producing a minimum of jolting over rough tracks and roads, but the physical conditions of the country made it impossible to bring ambulance cars very far forward, and this allowed a considerably longer period to elapse from the time when a man was wounded to the time when he reached the operating centre than was usual in other theatres of war.

The general treatment of wounds followed the evolution seen in other theatres of war. At first the ordinary eusol dressing was most in use. Then hypertonic solutions and salt packs were tried, and finally Carrel's method of treatment became the method of choice. Little could be done in the regimental aid posts and field ambulances beyond the sterilization of the injured area and the application of the dressing. Carrel's method was, however, commenced in the casualty clearing stations as the standard method of treatment. At the base hospitals the process of sterilization was continued, nor was it interrupted during transport by ambulance train or other means to the base. At the base, suture was carried out whenever the bacteriologist reported the wound ready for it. In addition, an orthopædic convalescent depot was formed and as soon as the wound was soundly healed, massage exercises, electricity and restorative work were undertaken, on the lines laid down by Sir Robert Jones. Secondary operations were necessary in a certain number of cases, mainly for correction of deformities or for the repair of damaged nerves.

Pro-flavine and brilliant green and bismuth iodoform paste were also employed, but the use of the last was reserved only for those wounds in which sterilization and suture had been impossible or had failed.

Patients with head injuries were operated upon as early as possible and were kept for at least fourteen days in the unit where the operation took place, which might either be a casualty clearing station or a stationary hospital. It was found that cases with penetrating wounds of the chest bore transport badly over long distances and they too were kept as a rule for at least fourteen days in the casualty clearing station before commencing their journey by easy stages to the base. On the other hand, when evacuation was possible by train, uncomplicated cases were sent down after the third day.

With regard to penetrating wounds of the abdomen, the principle of early operation was in force whenever possible from the very commencement of the campaign. But notwithstanding the difficulties of recovering the wounded in certain areas, the majority of the cases reached the casualty clearing stations within twelve hours of injury. Captain E. G. Gauntlett reported a series of 28 laparotomies for penetrating wounds, with 15 recoveries. In 14 of these cases perforations of the intestine were sutured and 11 recovered. During the same time 45 cases of penetrating abdominal wounds were admitted to the base hospitals, 33 of which had been operated upon in casualty clearing stations and recovered; 23 involved the small intestine, 5 the large intestine, and 7 the solid viscera. Of the remaining 12 cases which were operated upon at the base 9 recovered.

In no case of compound fracture, in which Carrel's treatment was started at the casualty clearing station, was the limb lost, and in the majority of cases of fractured femur, the wound had healed and the men were up in walking splints from five to seven weeks after the injury.

Gas gangrene occurred to a greater extent than was anticipated from the nature of the country. There was an immediate rise in the number of cases as soon as the troops had reached villages and cultivated soil, and also after the onset of wet weather. In one casualty clearing station, gas infection occurred in 3·98 per cent. of all wounds. The incidence of tetanus, on the other hand, was remarkably low.

In connection with the great incidence of malaria and dysentery, many cases simulated appendicitis and the abdomen was occasionally opened following a mistaken diagnosis of appendicitis.

It was found that the prolonged heat of the Macedonian summer influenced the healing of wounds, and also that the enervating effect and prevalence of malaria certainly diminished the resistance to infection, so that the men wounded in the autumn did not on the whole show the same recovery as those wounded in the spring.

With regard to Serbian patients, appendicitis was found to be comparatively rare as compared with the British. Herniæ were common. As regards wounds, the Serbians proved excellent surgical patients. Their recovery from shock was rapid, they stood major operations well, and septic wounds healed very satisfactorily. Anæsthetics were taken excellently and pulmonary complications were rare. Approximately

7 per cent. of shell wounds amongst the Serbians developed gas gangrene, and tetanus occurred approximately in one case in every thousand wounded, with a mortality of 45 per cent.

An International Surgical Society was formed under the presidency of Médecin-Inspecteur Ruotte, the Director of the French Medical Service in Salonika, and meetings were held once a month.

CHAPTER XIV.

WOUND TREATMENT IN HOSPITALS IN THE UNITED KINGDOM

IN the following description of the evolution of the surgical treatment of wounds in hospitals in the United Kingdom during the war, regard has been paid to the main factors which influenced the progress of wound treatment as a whole rather than to the details of special methods. Attention, in short, has been directed to the principles which underlay the new developments in military surgery rather than to the results obtained by various methods of treatment in different kinds of wounds and in different regions of the body. With this object in mind, the problem has been considered from two points of view, first a consideration of the surgical and physiological factors, such as the nature and age of the wound, the kind and virulence of the infection and the character of the treatment adopted before admission to the hospital, and, secondly, a review of the administrative factors, such as the supply and distribution of medical officers, the classification and distribution of the wounded men in so far as these factors exercised any influence on surgical treatment.

In the early days of the war before the machinery necessary for dealing with large numbers of wounded men had been established in France, it was a fairly common experience in the hospitals at home to receive within 24 or 48 hours after a battle large numbers of wounded British and Belgian soldiers suffering from heavily infected wounds. As the evolution of the necessary administrative machinery progressed, and as the experience of medical officers working in the front line overseas increased, wounds which came through to the hospitals in the United Kingdom began to show considerable improvement in their condition on admission. Instead of being pus cavities with sloughing walls, containing detached bone fragments, foreign bodies and pieces of clothing in their recesses, the whole forming a favourable culture medium for the growth of anaërobic and other organisms, they were received as surgically treated, not yet excised, but still drained cavities, emptied of gross contamination and foreign bodies, less foul in appearance and smell, freely suppurating, but fairly healthy granulating wounds. This change coincided for the most part with the

tentative and partial attempts made overseas at this time to cleanse wounds by mechanical, that is, by surgical means, and also with the substitution of more physiological methods for the use of strong antiseptics in the treatment of war wounds.

At a somewhat later stage, as the casualty clearing stations became more perfect as treatment centres, the wounds on arrival at home showed a still greater improvement. The previous almost universal anaërobic infections gradually gave place to the coccal forms. The wounded men showed less constitutional disturbance. The immobilization of fractures, especially of compound fractures of the femur, became more efficient with the wider use of Thomas' splints. At a later stage still, in 1917 and onwards, the practice of the mechanical sterilization of recent wounds by surgical excision in many cases, the efficient cleansing by mechanical means, and the removal of foreign bodies, devitalized tissues and detached bone fragments in others, had a most marked effect on the condition of the wounds and the wounded men as seen on arrival at home.

A certain proportion of flesh wounds and wounds involving joints, especially the elbow and the knee, arrived in England at this time in a healed or healing state, with the synovial membranes sutured and the joint cavities shut off from communication with the skin wound. In a considerable number of cases the sterilization of the wound by the removal of the foreign bodies and the excision of devitalized tissues had been carried out in the casualty clearing stations, while in others, in which the wounds were associated with extensive injury to bones, or communicated with the large serous cavities, the infective process had been controlled and limited by the same means.

It was very striking to observe at this stage of the war how the surgical outlook and the practice of medical officers working in hospitals at home gradually responded to the influence of the wider experience and better technique employed by their colleagues at the front. It is true that this response did not occur in all the home hospitals with equal promptness. In different hospitals it varied according to the previous training, age and surgical instinct of the medical officers. There can be no doubt that the employment on a large scale of the method of sterilizing recent war wounds by mechanical as opposed to chemical methods brought about a revolution in military surgery. The effect of this improved method on wound treatment at home was not, however, so immediately

striking. This was due chiefly to the fact that the wounds when they reached the home hospitals were no longer "recent" wounds. They had either been excised, in which case they were already healed or healing, or they were no longer in a condition in which excision of the infected walls was either practicable or likely to be successful. This point leads up to a consideration of the part played by the "time interval," that is, the age of the wound, in determining methods of treatment.

It is not necessary to dwell on the absolute length of time which elapsed between the infliction of the wound and the reception of the wounded man in one or other of the home hospitals, the point of importance being that no wound remained in a stationary condition. During the critical interval which passed between the injury and the reception of the patient in England, every infected wound progressed towards recovery or retrogressed to a more infected condition. These two phases alternated, or one replaced the other temporarily or permanently in many wounds. Every wounded soldier who reached a home hospital, no matter from what front he came, had undergone a sea voyage and in many cases, a long additional railway journey. This prolonged transport with its frequent changes of body and limb posture acted as an unavoidable but serious source of disturbance to wounds, especially in the earlier days of the war before the great value of efficient immobilization, not only of compound fractures but of flesh wounds, was sufficiently appreciated. The injurious effects of this prolonged transport on wound infection and wound repair were frequently seen in cases in which the Carrel-Dakin technique had been commenced overseas and imperfectly carried out during the journey. The instillation tubes in some cases lay on the skin surface at a distance from the actual wound, and the absence of free drainage through dependent openings, which is an essential feature of this method, was in itself a disadvantage under conditions in which the full technique was not, or could not, be carried out. This method, indeed, which, as a form of treatment of war wounds, was of great value in certain circumstances, showed serious drawbacks when the disturbances due to rail and sea transport had to be surmounted.

On the other hand, the disturbing effect of transport on wounds was much reduced when the method of surgical excision and primary suture became generally adopted at the front. Wounds which had been excised and sutured, and those

which, although not immediately sutured after excision, had been lightly packed and thus placed in a favourable condition for delayed primary suture, travelled well and reached the home hospitals in good condition. Many of the wounds which had been primarily sutured had already healed or were rapidly healing on arrival and others in which closure had been delayed were in a healthy granulating condition.

The beneficial results of this method of sterilization by mechanical means, together with the immobilization of fractures and of wounds of soft parts, soon became apparent in the improved condition of the wounds when the patients were admitted to the home hospitals. In attempting to estimate the value as a whole of any method of wound treatment, it is very necessary to bear in mind not only the immediate effect of the proceeding on the wound itself but also its influence in enabling the wounded man to bear without undue injury the disturbing effects of transport. A wise discretion in the employment of immediate closure of wounds, in which there was reason to think that the initial excision might not have been fully successful in removing the sources of infection, was associated with a corresponding improvement in the condition of the wounds as they arrived in England. Experience in the home hospitals showed that where attempts at excision had failed to arrest the infective process, those wounds which after excision were packed with sterile or antiseptic gauze and thereby placed in a favourable position for later closure did better in the end than those which had been immediately closed. These latter wounds tended to break down under the strain of transport and required to be again dealt with by mechanical or chemical means.

It is necessary to remember at the outset that all the unhealed, that is the still infected wounds, when admitted to the home hospitals were passing through, or had already passed through, a stage of physiological reaction to injury. A response was being made in the wound by the natural defensive mechanism of the body to the infective process, and this response varied in intensity and in efficiency in different wounds and in different patients. In every case this defensive reaction resulted in the formation of a certain amount of granulation tissue, composed essentially of emigrating leucocytes of various kinds, of proliferating connective tissue cells, and of newly formed capillary blood vessels. Even in wounds with walls composed of bruised and devitalized tissues, an area infiltrated by living cells

and a zone of granulation tissue would be found between the dead and the living tissues before the sloughs could be separated and thrown off.

The extent to which this physiological defensive reaction had taken place, or in other words the presence or absence of granulation tissue in any wound, provided a means of judging, from a physiological point of view, whether the wound was old or recently inflicted when admitted to the home hospital. Nor is this question of the presence or absence of granulation tissue a mere matter of academic importance. Speaking generally, the great problem of the efficient sterilization of the infected wound largely depended on the degree to which this physiological defensive reaction had proceeded in any given case. The results of chemical or mechanical sterilization were good or bad, easy or difficult, according to the extent to which the walls of the wound were lined by granulation tissue. The problem as to whether the infecting organisms were present only in the discharges and on the surface, or were embedded in the walls of any wound, depended not only on the nature of the infecting organisms and the length of time they had been growing in that wound, but also on the extent of the defensive reaction and on the thickness of the barrier of granulation tissue formed to arrest the growth of the pathogenic organisms. In recently inflicted wounds, up to eight or twelve and in some cases twenty-four hours after injury, the organisms were found in the blood clot and other contents of the wound cavity. They lay on the surfaces of the walls, having probably been carried by the missile or by indriven particles of clothing or by detached bone fragments into the recesses of the wound. They were confined for the most part to the situations and areas to which they had been carried and had not as yet permeated the living tissues which surrounded the bruised and devitalized area. The recently inflicted wound was often grossly contaminated, but was not necessarily infected. By the time these patients reached the home hospitals, however, all the wounds which had not been surgically treated, and a certain number of others in which for various reasons surgical excision had failed to bring about sterilization, were no longer merely contaminated, but had become infected wounds. The organisms had become embedded in the granulation or scar tissue, and were interned in the barrier of proliferating and emigrating cells which lined the cavity and formed the walls of the wound.

There were practically only four ways in which organisms

could reach the living tissues which bound the cavity of a wound. They might be conveyed thither by (*a*) their own activity, that is by direct extension and continuous growth ; (*b*) by the lymph or blood streams ; (*c*) under certain conditions by wandering cells during the process of the " return immigration " of phagocytes from the surfaces of the wound to the deeper tissues; or (*d*) possibly by the growth of granulation tissue around the organisms. In any one or all of these ways the organisms might become embedded in the granulation tissue which later on became the scar tissue. Moreover, in this state, too, the organisms were protected against the antiseptic action of chemical reagents to a far greater extent than when lying exposed in the cavity or on the surfaces of the wound during the first few hours after the infliction of the injury. Further, the organisms might remain in a state of arrested activity in the interior of leucocytes, endothelial or other phagocytic cells, or they might lie in dead spaces amongst the fibroblasts in the newly formed scar tissue. There is evidence, too, that a close association existed between this internment of organisms within the granulation or scar tissue and the occurrence of what is known as " latent infection," and the recrudescence of a local sepsis in healed or partially healed wounds.

Surgical interference, accident or the too violent movement of the limb or affected tissues, sometimes brought about the breaking down of this barrier tissue, and any lowering of the vitality of the germ-laden phagocytes or tissue cells by cold, by chemical agency, or by mechanical injury might be followed by the escape and renewed growth of the interned organisms. This " recrudescence of local sepsis " seemed especially apt to occur in patients in whom the antibody content of the blood plasma to the particular strain or organism present was not high enough to inhibit a renewal of its growth under the more favourable conditions set up by the fresh injury to the body cells.

The important fact that organisms not only lay in the cavity or on the surfaces of a recently inflicted wound but were also embedded at a later stage in the granulation tissue of the walls of the wound, made mechanical sterilization by surgical means a safe and efficient remedy in recent wounds, but a difficult and less satisfactory method of treatment in older wounds. The presence of this granulation tissue was not only, however, an important factor in the classification of wounds according to age and degree of physiological reaction, but it was also largely

responsible for many of the difficulties that confronted the surgeon at a later date. As a first line of defence and as an essential factor in protecting the body against an overwhelming attack by organisms and their toxins, it was of enormous importance in the early hours or days of the injury, but later when organisms became embedded in this barrier it had serious disadvantages as it rendered the efficient sterilization of the wound by artificial means much more difficult. Hence arose the somewhat paradoxical conclusion that " the older the wound, or the more fully established the physiological reaction, the greater the difficulty in efficient sterilization by artificial means." This want of harmony between natural and artificial methods, between natural defence and surgical aid, evidently showed that attempts at chemical sterilization were too crude. In some cases they might even run counter to, rather than coincide with nature's methods of bringing about resistance and recovery.

It is of interest, therefore, to consider in somewhat greater detail why it was that wounds which had reached the granulating stage were so difficult to sterilize by either mechanical or chemical means. First, with regard to mechanical methods, the surgical difficulties surrounding the operation of excision of the wound were themselves greater. The distinction between granulation or scar tissue and healthy tissues was only recognized with difficulty in the older wound. In the recent wound, on the other hand, the devitalized tissues presented a characteristic appearance to the eye of the experienced surgeon ; they did not bleed when incised and could thus be differentiated from living tissues, which looked quite different and bled freely. Further, important structures like nerves and large blood vessels were not only covered by but were often incorporated in the granulation or scar tissue and could not be exposed or defined with the same facility as was the case in recent wounds. Consequently they were very apt to be injured during the process of excision of the wound, and even if they did escape injury, the close proximity of such important structures might convert into a partial what should have been a complete operation. Then again, any injury to this barrier tissue by operation, unless it had been completely removed, was itself apt to set up a recrudescence of the infective process, a so-called " flare " in the wound. The possibility and the dread of this occurrence caused great anxiety to the surgeons and were amongst the chief drawbacks in the treatment of war wounds in home hospitals. In recently inflicted wounds on the other hand, as

seen in dressing stations and in casualty clearing stations these difficulties were absent or much less serious.

Secondly, with regard to chemical methods of sterilization, the presence of this barrier of granulation and scar tissue containing organisms in an inhibited state of activity afforded some protection to the microbes and shielded them from the full antiseptic effect of chemical substances introduced into the wound. Peyton Rous and others have shown that pneumococci introduced experimentally into the circulation of animals were ingested by phagocytes and were carried to the liver and other organs where they were interned and protected from the full effect of the immunizing substances present in the blood. Owing to the influence of this barrier tissue on both mechanical and chemical methods of sterilization, it is thus true to say generally that mechanical methods have been characteristic of wound treatment as practised at the front and in casualty clearing stations, while chemical methods, supplemented in some cases by closure of the wound with or without partial excision at a later stage, have been chiefly employed in base hospitals. From the practical point of view, however, an infected wound presents a double problem, one aspect of which relates to the treatment of the cavity, the other to the treatment of its walls. Though mutually interdependent, the surgical measures necessary for the efficient treatment of the cavity were not necessarily those which were best in the treatment of the walls of the same wound. In a certain sense the surgeon was in a position of advantage in dealing with the cavity while he might be confronted with great difficulty and might do much harm by interfering too vigorously with the walls of any but the most recent wounds. Moreover, these difficulties increased with the age of the wound, that is with the development of the physiological reaction, and with the formation of granulation and scar tissue in the walls of the wound.

In the early days of the war surgeons working at the front dealt with the cavity of a wound by drainage or other surgical methods and left the walls alone. This method of treatment failed to control wound infection, and they then began to deal with the walls of the wound as well as the cavity. They excised bruised and devitalized tissues and they found that this method, when efficiently carried out within a short time after the infliction of the injury, allowed them at once to close wounds so treated and thus exclude opportunities for renewed infection. It was this discovery that brought about the great revolution in wound treatment of the war. Surgeons

working in some hospitals on older wounds, on the other hand, could deal efficiently with the cavity of the wound by mechanical in combination with chemical methods, but they were greatly hampered in dealing efficiently with the granulation and scar tissue which formed its walls. This difficulty in sterilizing the walls of older wounds was more associated with faulty action or over-action of the defensive mechanism in forming an excessive amount of granulation or scar tissue than with the number and kind of organisms present in the wound.

The important factor to bear in mind seemed to be the intimate association which existed between the treatment of the cavity and the treatment of the walls in both recent and older wounds. An undrained cavity containing putrid or putrescible material was incompatible with healthy walls. But while the efficient treatment of both cavity and walls could be successfully undertaken at the same operation in recent wounds, a preliminary drainage of the cavity combined with irrigation with chemical reagents might with advantage precede the treatment of the walls, and the eventual closure of older wounds. The fact that a close association exists between surgical difficulties in sterilization and the presence of granulation tissue accentuates the importance of earlier preventive measures, such as surgical excision, in dealing with recent wounds. The prevention of the formation of granulation and scar tissue is a further result of the treatment which has for its aim the prevention of infection in wounds.

The presence in wounds of this granulation and scar tissue, however, with the pathogenic organisms interned in it, had a further important influence on wound treatment. It not only added to the difficulties of mechanical sterilization by surgical means, it not only protected the ingested organisms from the full effect of germicidal substances and so rendered attempts at chemical sterilization ineffective, but it also exercised an important bearing on the form in which these chemical substances were likely to be most efficient, and on the method of their application. Attention has already been drawn to the fact that the organisms were carried into the granulation tissue not only by direct growth, or by the blood and lymph channels, but also by transportation by wandering cells during the return-immigration of phagocytes from wound surfaces. But these phagocytes not only ingested bacteria and cocci, they also took up pigment particles or other foreign substances introduced into the wound. They could be seen

under favourable experimental conditions to contain iodoform or bismuth grains, globules of liquid paraffin, reduced iron, or other substances if these were not too injurious to cell life. Inasmuch then as the return of these cells into the tissues bordering the wound cavity has been shown to take place, this return journey of loaded cells might afford one way in which antiseptics in the solid or semi-solid state might gain access to the tissues bounding the wound. It was thought by some surgeons that iodoform, liquid paraffin and bismuth, in the form of a cream or paste when introduced into the wounds under certain conditions, did exercise an inhibitory effect on the growth of the infecting organisms. It is possible that some of the antiseptic effects of these substances used in this solid form might depend on the fact that they were thus carried into the tissues. Antiseptics like iodoform in the solid form seemed to be of especial value in the treatment of older wounds in which germ-laden granulation and scar tissues abounded.

With regard to the means employed to overcome difficulties of physiological and pathological origin, the difficulties in the mechanical treatment by surgical excision of these granulating wounds were so great that surgeons working in the home hospitals were naturally led to employ chemical methods of sterilization. They tried by the use of antiseptics of the " explosive " or rapidly acting hypochlorite type or of the more slowly acting " depôt " type, such as the B.I.P. paste, to sterilize wounds, but whatever the method of chemical sterilization employed they soon found that, in order to prevent re-infection and the overgrowth of granulation and scar tissue and the serious injury to delicate tissues which the continued use of antiseptic dressings involved, it was necessary to take steps to close these wounds by secondary suture at the earliest opportunity. There is reason, however, to believe that this practice of closing granulating wounds by secondary suture, after a preliminary sterilization of the wound by chemical means, was not employed as fully as it might have been, at any rate in the earlier stages of the war. No doubt the number of failures after attempts at such secondary closure was considerable. Medical officers were not thoroughly conversant with the best technique to be employed. Some did not seek the help which the bacteriological laboratory could give them concerning the kind and number of organisms present in the wound and the right time for closing it. Others were deterred by the dread of provoking a recrudescence of the local sepsis, a possibility always present to the mind of surgeons called upon

to undertake the treatment of these granulating wounds. Still, in spite of all these reservations and difficulties the aggregate length of time during which large granulation wounds were allowed to remain unclosed, subject to all the attendant risks of reinfection and to the certainty of an abundant formation of scar tissue, underwent a very appreciable curtailment in the hospitals in the latter days of the war.

The effect on wound treatment in the hospitals in the United Kingdom during the war of certain administrative factors, such as hospital organization, the supply and distribution of medical officers and the efficiency of the nursing and allied services, requires consideration. At the beginning of the war the total number of surgeons with knowledge and experience of surgical methods in wound treatment was limited. Very little use had been made in times of peace of the great opportunities afforded by the civil hospitals for educating the main body of the medical profession in surgical principles and in the application of these principles to civil practice. The surgical material present within the walls of these institutions had been available only to a few medical men in each university centre, large city or county town, with the result that the general practitioners in the district from which these hospitals drew their supply of patients had to a considerable extent lost touch with modern surgical methods. This did not occur to quite the same extent in certain industrial areas and mining districts where frequent and severe accidents had kept alive among the practitioners familiarity with injuries and skill in dealing with their effects. Moreover, at the beginning of the war the enormous influx of wounded men almost swamped the available accommodation in the rapidly organized and hastily equipped military hospitals, formed in many cases out of partially and hurriedly adapted public buildings. Large numbers of medical officers suddenly found themselves responsible for the supervision and treatment of one or two hundred or even more wounded men, with wounds of every degree of severity in all parts of the body, and those few medical officers who had been engaged in surgical practice before the war took their part on an equal footing with other colleagues in the routine care of wards.

As an unavoidable result of this arrangement large numbers of wounded men came under the care of medical officers whose previous experience had been limited to general practice in towns where all injuries and accidents of any degree of severity had been removed to the care of the surgeons in the county

hospital. In the early days the activities of trained surgeons were confined to routine work in their own wards instead of being available for consultative and operative purposes throughout the hospital. Specialization of men and methods did not take shape in the military hospitals at home until a much later period and not until experience of the value of the newer co-operative methods in use overseas had been realized. As a direct consequence of this sudden entrance of large numbers of general practitioners into the highly technical field of surgical work, with the added difficulties which arose from the severe nature and virulent infection of the wounds, medical officers in these surgical wards were obliged to learn by experience. A few of the medical officers gained this very necessary skill and knowledge quickly, a considerable number more slowly, and a certain number never gained it at all.

This inadequacy in the supply of medical officers whose training and hospital experience entitled them to rank as practical surgeons was further accentuated in two directions. Owing to the urgent needs of the army in the field and to a natural desire for service in the field, many of the keener and younger surgeons had already taken up work in France or elsewhere, thereby reducing still further the available supply of surgeons at home. Moreover, as an outcome of the territorial and local system on which the personnel of the hospitals was organized during peace, the distribution of the surgical talent available in the country in relation to the number of beds for wounded in different centres was at first very unequal. Surgeons were collected in groups round the teaching hospitals and medical schools and had not yet been mobilized for service in all the centres where wounded men were congregated, while some towns, with good railway communication and institutional accommodation and with local organizing and administrative ability, rapidly grew into large centres for the reception and treatment of wounded men. As a consequence of this unequal aggregation of surgical specialists the hospital accommodation in these towns soon reached two, three, or even four thousand or more beds, while the number of medical officers who could properly be called surgeons remained limited. This unequal distribution of surgical experience and skill had a very important influence on war surgery in the hospitals in the United Kingdom in the early days of the war. Medical officers whose experience had been limited to the injuries seen in civil practice were at a disadvantage when confronted with the many cases of huge lacerated and virulently infected

wounds and compound fractures which poured in from France and Flanders. Consequently, for the first nine or twelve months of the war, wounds which involved the body cavities primarily, or secondarily by extension, did badly because owing to imperfect surgical methods the spread of the infection and the pressure effects of retained infected fluids brought about serious damage to vital organs. It was only when some knowledge of the methods and results obtained by medical officers abroad reached the hospitals at home that the treatment of wounds, of the thorax for instance, with their complications can be said to have reached a fair level of excellence.

Not only were the medical officers who could be called surgeons too few in number and unequally distributed in relation to the wounded, but the services of such as were available at any given centre were not employed to the best advantage in the early days of the war. If their knowledge and skill had been employed in the diagnosis and treatment of the more serious and difficult cases, and in supplementing by consultation, and where necessary by operation, the surgical work of their less fully trained colleagues, much benefit would have accrued to the hospital staff as a whole as well as to the patients.

In many hospitals in the early days of the war and in some for a considerable period afterwards, the supplementary services rendered by the pathological, X-ray, electrical and massage departments were only struggling into shape. The want of bacteriological information as to the condition of the wounds, and the imperfect co-operation between the medical officers and the laboratory workers seriously influenced the diagnosis and the treatment of many wounds. In the X-ray department the full value of the help that radiology could render to military surgery was not at first obtained, partly because the officers in charge of the X-ray department were, in some cases, general practitioners, unfamiliar with the special problems presented by war wounds. In the massage departments, too much reliance was placed in the early days on passive movements, on massage and on other mechanical processes. Too little attention was given to instructing the patient regarding his share in the remedial exercises, and to encouraging him to initiate voluntary and active movements of a purposive kind. As a consequence of this, the time and energy of masseuses and nurses were partly wasted or directed into wrong channels.

For the efficient treatment of difficult cases of fracture or

dislocation associated with suppurating wounds, the services of a trained mechanic with some knowledge of making and adapting various kinds of splints, extension apparatus and other surgical appliances, would have been of very great value if more freely available. Such a supplementary mechanical service should include workrooms and fitting shops, and there can be no doubt that the results of the treatment in many cases would have been better and the length of stay of the wounded men in bed or hospital materially shortened if medical officers could have had the advantage of such an equipped mechanical service at each of the larger hospitals at an earlier stage in the war.

The absence at first of facilities in many hospitals for the making and fitting of pylons and other temporary appliances for use after amputation, together with a want of appreciation on the part of some medical officers of the value of such apparatus, led to much delay in re-establishing the functional activity of muscles and the vigour of the circulation and, as a consequence, delay in the healing of amputation stumps. It was also responsible for the prolonged retention in bed of patients who ought to have been moving about, and thus for a further delay in the fitting of permanent artificial limbs.

The importance of the preventive element also was not at first appreciated in orthopædic work. It was only at a later stage, largely through the labours of Sir Robert Jones and his co-workers, that it began to be realized that every surgeon and every medical officer in charge of wounded soldiers must work not only on orthopædic lines, but on orthopædic lines of a preventive as well as of a curative kind. It gradually became clear that these preventive methods must also be commenced in the early stages of wound treatment, soon after the infliction of the wound, if the limiting and disabling effects of injuries to bones, muscles, tendons, nerves, and other structures were to be minimized or done away with.

Reference has been made to the absence of co-operation between the medical officers working in the same hospital. The outlook and responsibility of the individual officer was at first limited to the ward under his supervision and there was a marked absence of team work. This applied, however, not only to the work of the individual hospital, but extended also to the relationship between different hospitals in the same command. The spread of knowledge and the application of improved surgical methods on a wide scale was hindered by

this isolation of units and of medical officers in hospital units, and it was only after the lessons, which had been learned in the casualty clearing stations and hospitals abroad regarding the great value of team work, reached the home hospitals that improvements followed. It is possible that a more extended use of the practice of interchange between medical officers serving abroad and those serving at home might have helped to speed up the spread of knowledge as to the best methods of wound treatment.

The value of classification followed by specialized treatment of wounds of different parts of the body and of different degrees of severity was recognized early in the war, but it was not till a much later stage that a co-ordinated attempt was made in the large military hospitals at home to sort out the wounded according to the nature of the wound or to the special kind of treatment needed in different cases. Head cases, thorax cases, fractured femurs and general wounds were at first treated in general wards, and it was only later that, following on the experience gained abroad, wards were set apart for fractured thighs, or for head, chest or abdominal injuries. This absence of classification undoubtedly tended to delay progress in the surgical work of the medical officers, and it also hampered efficiency in the nursing service. Consequently it was only when special hospitals and special wards were organized for the treatment of different kinds of wounds that the best results were obtained.

Medical officers gained experience as the war progressed from personal contact with wounded men in the wards. It gradually became apparent to the most conservative of them that certain methods tended to increase rather than to limit the spread of infection in heavily infected war wounds, and that different methods were helpful or harmful according as they aided or hindered the natural defensive mechanism of the body. The "healthy," or the "unhealthy" condition in which compound fractures and other injuries arrived after treatment by different methods abroad provided numerous object lessons of the supreme importance of observing certain fundamental principles, such as the adequate immobilization of compound fractures, and of the dangers which arise from the retention in wounds of putrescible fluids.

Apart, however, from the improvement which gradually occurred as the result of personal experience, the treatment of war wounds improved as a whole whenever steps were taken in any hospital or in any command to improve the classification

of the wounded, whereby similar wounds were treated in special wards and certain kinds of wounds in special hospitals. For instance, the treatment of compound fractures of the femur by special methods in special wards by medical officers with experience of that kind of injury not only greatly benefited the wounded but also brought about a general improvement in wound treatment, because the time and attention of medical officers and nurses in a general ward were not necessarily limited to a few very serious cases but became available for all the patients in the same ward. Unfortunately it was not until the last year of the war that the special methods and the special appliances found to be so useful in the treatment of compound fractures of the femur reached all the larger hospitals.

While there can be no doubt as to the great benefit which resulted from the establishment of special hospitals for orthopædic cases, it is also true that during the evolution of these new departments some check was given to surgical progress in some large general hospitals by an undue tendency on the part of administrative authorities to extend too widely the definition of an orthopædic case. The essential requirement was to get medical officers to understand that the efficient surgical treatment of the vast proportion of all wounds really involved the observance of orthopædic principles; and to get them to realize that it was often possible by rectifying disabling influences early in the case, to preclude the need for many of those remedial operations and restorative exercises which formed such a considerable part of the daily work of the orthopædic institutions. If all compound fractures of the femur had been treated on the most approved lines during the first few weeks after injury, there would have been a great reduction in the number of so-called orthopædic operations at a later stage to correct bony deformities and muscular and cicatricial contractions. If it had been possible at the beginning of the war, as it was at the end, to prevent or control the spread of the septic process in wounds in the early stage, then the remedial operations on nerves, tendons and other structures which were so numerous when the wounds were healed or healing, would also have been greatly reduced in numbers and would have been more successful in their result.

The value of a neurological and surgical combination in the diagnosis and treatment of the central and peripheral nervous systems soon became apparent, but it took longer

to demonstrate the importance of combining general surgical with bacteriological methods. Gradually it became clear, however, that it was unwise to treat all infected wounds by one surgical method when the kind and degree of infection varied in almost every wound. Good results followed the interchange of medical officers between military hospitals in France and those at home. Medical officers on their return from a casualty clearing station or a base hospital brought with them not only improved methods but increased keenness and a spirit of co-operation which were very helpful.

The organization at a later stage of the war of periodical meetings of the medical officers at some large centre in a command at which cases could be shown, and methods and results of treatment could be discussed, was of much value and would have been more so if it had been possible to organize the meetings at an earlier date.

In so far as administrative methods affected the surgical practice of the medical officers in the hospitals at home, the chief lesson learned by the experience of the war was that the training of the military surgeon in wound treatment must be undertaken during peace. This means that a sufficient number of the rank and file of the medical profession must be educated in the principles which underlie surgical practice as applied to the treatment of wounds in the civil population. In this way a basis of knowledge and of training in surgical technique would be commenced which could be readily extended to the treatment of war wounds and could be rapidly supplemented by the special methods which military surgery demands. In order, however, to obtain this experience and provide this training in times of peace a far more extended use has to be made for teaching and training purposes of the large amount of surgical material which finds its way into the civil hospitals of the country.

CHAPTER XV

WOUNDS OF THE CHEST.

THE experiences that have served as the basis of the following description of wounds of the chest were confined to wounds and injuries suffered by British troops in France and Flanders. Chest wounds in the Palestine campaign were chiefly caused by rifle bullets, for it was only in the second battle of Gaza and in the second operations east of the Jordan that the troops were confronted with an enemy entrenched in fortified positions. These bullet wounds apparently did almost as well as those in South Africa, the warm and dry climate lessening trouble from bronchial complications.

Shell wounds, however, caused laceration like that seen in France, and resulting empyemata were frequent. Thus Dolbey records 10 per cent. of empyemata in a group of cases received at a Mediterranean base seven days after they had been wounded. These cases presumably came from Gallipoli, and it appears that infection by anaërobic bacilli was uncommon in that campaign.

The total mortality of chest wounds in the war was not directly ascertained, but there can be little doubt that it was exceedingly high. Medical officers working in field ambulances and casualty clearing stations saw how rapid and early was the recovery of a large proportion of the men who had been shot through the lungs, and they naturally inclined to the belief that in most instances it was not a very serious matter to be hit in the chest. This view, however, neglected a very high mortality in the field. No figures on this point were collected in the British service. Sauerbruck gives the records of 300 dead on the field of battle, and states that 112 of these, or 37 per cent., were wounded in the chest. Presumably his figures refer to German casualties, though it is not stated whether they were incurred in open fighting or in trench warfare. A very similar figure, 29 per cent., was recorded by Löffler for 469 dead on the battlefield in the Danish War of 1864. It is therefore possible that about one-third of those who were killed in the field had been shot in the chest, but there are no figures on which really reliable statistics can be based. The high mortality on the field is

indicated by the fact that the proportion of chest wounds to all gunshot wounds admitted to No. 8 Casualty Clearing Station at Bailleul during the years 1915 and 1916 was approximately 3 per cent.

With regard to mortality in medical units there are reliable statistics. The figures that follow were not obtained from ordinary army returns but from special investigation in which the accuracy of the reports made was controlled, so far as possible, by officers who during the period of the returns were paying close individual attention to the subject.

The most complete returns were collected from August to October 1917, during the autumn fighting at Passchendaele. At this time surgeons at the casualty clearing stations were dealing freely with chest wounds, and the general arrangements for the early care of these casualties had been developed to a high efficiency. On the other hand, bad weather and delay and difficulties in transport from the field tended to make the general condition of the wounded worse.

Out of a total of 3,521 patients with gunshot wounds of the chest received in casualty clearing stations in this period of three months the case mortality was 17·2 per cent. The death-rate in the field ambulances, excluding the regimental aid post, during the same time was 7 per cent. Various statistics collected at different times in the base hospitals showed that the death-rate in chest wounds admitted to them from the casualty clearing stations was slightly less than 6 per cent. After transference to England deaths were so few as to be practically negligible. The total table of mortality from chest wounds would therefore appear during this period to have been as follows:—

At the field ambulance	7·0 per cent.
At the casualty clearing station, 17·2 per cent. of admissions = of survivors ..	15·9 ,,
At the base, 6 per cent. of admissions = of survivors	4·6 ,,
Total =	27·5 ,,

This general table of mortality in hospital unavoidably includes a number of cases where the lung wound was complicated by spinal or abdominal injuries and the latter had probably caused death; for in many cases the distinction could only have been established by an autopsy that was not made. But so far as was possible in a rapid classification of the casualties on first examination, cases with obvious and serious complications of their chest wounds have all been excluded.

These figures probably represent the best results on the average in chest wounds that were seen in the British armies during the war. But individual medical officers, who had devoted special attention to the care of these wounds and made themselves skilled in the choice and execution of the various methods of treatment required, obtained much better results than those shown in these broad figures. Reference is made later to their special statistics, which also show the true figures of mortality from lung wounds when all other complications were rigidly excluded, the percentage then falling to about 15.

The mortality in base hospitals on the lines of communication never varied greatly, as shown in the following figures :—

Date.	Base.	No. of Cases.	Deaths, Percentages of Admissions.
1916	Boulogne ..	676	5·8
1917	Boulogne and Etaples ..	711 (after operation at C.C.S.)	6·2
1918	Rouen ...	1,309	5·7
1918	Boulogne ..	548	5·2

The mortality was certainly higher in 1914 and 1915, when arrangements had not been made for the detention of men with chest wounds at the casualty clearing stations, and the bulk of them arrived at the base on the second or third day after the injury. During this period Bradford and Elliott found at Boulogne a mortality of nearly 10 per cent. in hæmothorax cases, the figure being of course less when all chest wounds were included. But when the practice was established of detaining chest wounds for a little time at the casualty clearing station, the base mortality remained steady at the lower figure, and it showed no considerable alteration in 1917 and 1918, when the surgeons at the casualty clearing stations were operating freely on the more serious types of these wounds.

The death-rate at the casualty clearing stations appeared to vary. In 1915, two casualty clearing stations at Bailleul found their mortality for chest wounds to be 10 per cent., and in 1916, Sir Wilmot Herringham recorded a very similar death-rate in a series of 211 consecutive cases observed by him from the fighting on the Somme. But later records from casualty clearing stations situated a little nearer to the line, where even severer types of chest wounds were

received directly, gave a death-rate of about 20 per cent. It is probable that during the earlier period a much larger proportion of men with serious wounds was retained in medical units in advance of the casualty clearing stations. No analysis was made of the field ambulance returns in 1915 or 1916, so as to reveal the proportion of chest wounds that died in these forward medical units. It is, however, unlikely in view of the relatively low mortality (10 per cent. at this time at the casualty clearing stations), that the total death-rate, even in the first year of the war, was more than one-third of those who survived to reach any medical unit.

When Pierre Duval, in 1916, began his forceful advocacy in the French army of the need for early surgical operations in order to save the lives of casualties from chest wounds, he used figures suggesting that in the French army the total mortality from chest wounds was at least 50 per cent. when the deaths at successive medical units from front to rear were added together. The mortality for these wounds during the war was certainly much higher than surgeons had anticipated from their experience of the South African War, and owing to this pre-formed opinion it was long before any one realized how high was the actual mortality ; but it probably never reached in any of the Allied services the figure put forward by Duval.

In comparison with the British figures it is useful to quote the extremely accurate statistics given by Depage from the Belgian Red Cross Hospital at La Panne. This hospital was so close to the trenches that patients were received in it from two to six hours after being wounded, and since it did not form part of the ordinary evacuation stream, or rather was not subjected to shell-fire, casualties could be detained in it until they had reached convalescence. In a series of 320 chest wounds observed before the time when extensive thoracic surgery was in vogue, there were 59 deaths, that is 18·4 per cent. Half the deaths occurred in the first twenty-four hours from hæmorrhage and shock. In comment upon these relatively satisfactory figures Depage emphasized the fact that rather more than half of the casualties had, in such desultory fighting as obtained on that particular sector of the front, been caused by rifle bullet. And he gave the important analysis that the mortality for thoracic wounds by rifle bullet was only 11 per cent., whereas it was 29 per cent. for wounds by shell fragments.

The wounds treated in the British area were caused by rifle and machine gun bullets, by shrapnel balls, or by fragments of high explosive shell, grenade or bomb—very rarely indeed

by bayonet. The relative frequency of the wounds caused by rifle bullet or by shell fragments varied greatly with the type of action. In a war of movement the percentage of wounds by rifle bullets was high; in stationary trench warfare shell or bomb wounds preponderated.

Thus in a series of 631 cases of gunshot wounds of the chest recorded by Major W. L. Mann from No. 3 Canadian Casualty Clearing Station at Rémy Siding, behind the Ypres salient, during the period from January 1916 to November 1917, the wounds were apportioned as follows:—

Smooth missiles, rifle bullet and shrapnel ball	17·3 per cent.
Rough missiles, shell, bomb, grenade ..	82·41 ,,
Bayonet	0·16 ,,

In the summer and autumn of 1918, however, when fighting had reached an open character, the missiles recorded for 1,023 cases at the Rouen base, after elimination by death at the casualty clearing station of some larger proportion of the shell wounds, were:—

Shell fragments	580 or 56·7 per cent.
Shrapnel ball	13 or 1·3 ,,
Rifle bullet	423 or 41·3 ,,
Unknown	7 or 0·7 ,,

Certain figures from the Boulogne base for wounds received in August 1918, showed with regard to 337 hæmothorax cases that the cause had been bullet wound in 190 cases, of which 7·9 per cent. developed empyemata; and shell fragments in 147 cases, of which 15·6 per cent. developed empyemata.

Wounds from fragments of shell were often multiple, and, being caused by irregular rough edged fragments of metal, which carried shreds of dirty clothing into them, were more frequently complicated by the development of sepsis. The multiplicity of the wounds by shell and the greater laceration of the tissues probably caused them to be much more fatal on the field itself than those by rifle bullet. On this point, however, there is no information. With regard to survivors from the field, Depage's figures showed that shell wounds have rather more than twice the fatality of bullet wounds.

Death in the first twenty-four hours, whether on the field, or in medical units, was due to the severity of the injury with hæmorrhage and shock. All the deaths in field ambulances and at least one half of those occurring at casualty clearing stations were so caused. Thus at No. 3 Canadian Casualty Clearing Station, Mann found that 57 per cent. of the deaths

took place within the first forty-eight hours after receipt of wounds. Deaths subsequent to the second day, that is in the remaining 12 per cent., including all those who succumbed at the base hospitals, were almost invariably due to sepsis. Thus death might be caused by an acute infection of the blood effused into the pleural cavity with resulting septicæmia, or it might be due to broncho-pneumonia or a purulent bronchitis. Hæmorrhage from the wound, either in the chest wall or in the lung itself, never continued after the first day; and the very few deaths that did occur from hæmorrhage at a later date were due to fresh bleeding where sepsis had opened up some vessel, either in the chest wall or in the lungs.

Mortality in previous Wars.

There are no reliable statistics of the mortality of chest wounds prior to the period of the Peninsular War, though various writers make reference to the fatal character of penetrating wounds. Such figures as have been recorded from various wars in the hundred years preceding 1914 cannot be very usefully compared, for some of them apply to immediate survivors from the field of battle, whereas others are concerned with men seen in hospitals at a later date, when death had already eliminated the more seriously wounded. No figures state the mortality in the field, or the total deaths in all medical formations. But it is very evident that up to 1900 there was every reason to regard a chest wound as an injury of a very serious nature.

In the Peninsular War, after the battle of Toulouse on 10th April, 1814, 106 cases of chest wounds were admitted to the hospitals in Toulouse. Of these, 14 returned to duty, 57 were invalided to England, and 35 died—a mortality of 33·01 per cent.

In the Crimean War, Patrick Fraser gives 3·4 per cent. as the proportion of chest wounds to the total wounded in hospitals at the Crimea. This figure, resembling that recorded for the war of 1914–18, proves how high was the immediate mortality of chest wounds on the field itself. For those wounded in the chest the mortality in hospital, on a total number of 474, was 28·5 per cent., while the death-rate for actual wounds of the lung itself was 79·26 per cent. The French at this time were stated to have lost 91·6 per cent. of their actual lung wounds.

In the American Civil War more than 20,000 wounds of the chest were tabulated by Otis as having been treated in medical formations. The death-rate for all injuries of the chest,

including penetrating and non-penetrating wounds, was 27·5 per cent., while for actual penetrating wounds it was 62·5 per cent.

In the Franco-German War of 1870-71, MacCormac reports a death-rate of 54·8 per cent. for penetrating wounds at Sedan, and Fischer gives it as 55·8 per cent. at Metz.

From the above figures it will be seen that the mortality from chest wounds was very high; indeed, it was the opinion of some experienced observers that actual lung wounds were almost always fatal. In the wars of the next forty years, during which time the high velocity rifle was used, a very considerable diminution of the severity of gunshot wounds of the chest was recorded. It has been suggested that the lessened mortality was attributable to the introduction of antiseptic methods of treatment, which came into use at approximately the same time as did the small calibre rifle. Experience in the war of 1914–18, however, showed clearly that antiseptics had little to do with the improvement, for while wounds from rifle bullets had on the whole a favourable issue, those due to shell fragments were almost as bad as the wounds by musket balls had been in the Crimea.

In the Russo-Japanese War the wounds inflicted were mostly from a small calibre rifle. Lieut.-Col. W. G. Macpherson, R.A.M.C., in his official report to the War Office stated that the general principle of surgical treatment both in the front and in the base hospitals was expectant. Wounds of the chest were, as a rule, simple punctures, and they were classed as mild cases and not treated as serious unless secondary complications occurred. In front hospitals such wounds were dressed in the simplest manner, namely by a pad of gauze kept in place by strapping. Operations on the thorax other than those for empyema do not appear to have been done.

In the South African War, 1899–1901, wounds were almost entirely due to small calibre cylindrical rifle bullets, mostly at long range; the percentage of shell wounds was very low. In addition, the climate was good, the soil dry and clean and free from contamination with pathogenic bacilli. The picture of the condition of chest wounds for this war is entirely unlike that given for previous campaigns and the mortality rate was the lowest recorded. Sir George Makins writes of it thus: "In regard to prognosis, wounds of the chest furnished the most hopeful class of the whole series of trunk or visceral injuries. This was explicable mainly on two grounds: first,

the sharply localized character of the lesion produced by the bullet of small calibre ; and secondly, the fact that the lung, the most frequently injured organ, is not materially affected by the grade of the velocity with which the bullet strikes its elastic and practically homogeneous tissue. In point of fact, there is no reason why a perforation by a bullet of small calibre should be much more feared than a puncture from an exploring trocar, and the danger of the two wounds is probably very nearly the same." He states that " wounds from shrapnel and fragments of shell also did remarkably well." During the whole campaign he saw only a single case of primary empyema, and this was one which he attributed to infection introduced in an early operation for the removal of a bullet as it lay beneath the skin. On the other hand, secondary empyemata were supposed to have been caused in several instances by aspiration ; and there was a general belief in South Africa that aspiration was useless in addition to being dangerous, since the fluid was observed to have accumulated again after the first tapping. Aspiration therefore was condemned. Resection of a rib in order to dislodge intrapleural blood-clot was also, and rightly, forbidden, since secondary infections were then certain to be introduced. Primary empyemata rarely existed. So it was decided that chest wounds were best left to the natural processes of cure, and the cases recovered very well. No general statistics with regard to chest wounds in the South African War were published by the Medical Services, and Makins does not quote any recorded by him. Out of 214 cases observed by Stevenson, only 30 died—a mortality of 14 per cent.—but the proportion of these casualties in which empyemata developed is not stated.

The experience gained in the South African War inclined surgeons to a most conservative method of treatment for chest wounds. The campaign which opened in 1914 rapidly changed that teaching. High velocity, pointed, wedge-shaped bullets at short range, or tearing fragments of shell, caused greater laceration of the tissues than was seen in South Africa, and the effusion of blood into the thorax was often so large that it could not very well be left alone. The clothing and the skin of the soldiers were foul with soil and fæcal organisms, and from this source primary infection was very frequently introduced into the hæmothorax. Hæmorrhage would appear to have been, and sepsis most undoubtedly was, a much more serious matter in the prognosis of chest wounds than on the last occasion in which the British army was in the field.

Development of Treatment of Chest Wounds.

At the opening of the war in 1914, the general expectation of military surgeons was no doubt in harmony with the experience of Sir George Makins during the South African War, namely that chest wounds, apart from those which were immediately fatal, would not be of a very serious nature, and that they would chiefly require treatment on simple conservative lines. In the casualty clearing stations and the base hospitals these wounds were consequently placed under the care of the physician.

Within a very few months, however, enough evidence was accumulated to show that chest wounds were not doing well. No great attention was paid to those who died in the first twenty-four hours at the field ambulance or casualty clearing station of hæmorrhage or shock. They belonged to the general group of seriously wounded men, and their deaths seemed unavoidable, while their considerable number was not adequately realized. But apart from these apparently hopeless cases there was a later death-roll from septic complications of the wounds, chiefly by the change from a simple hæmothorax into an infected empyema, which amounted to fully 10 per cent. of those who had survived the immediate dangers of hæmorrhage and shock. These septic empyema cases were peculiarly disappointing. The change to the infected state might appear with great rapidity on any day in the first week and in a patient who up to that time had promised a smooth and easy recovery. Moreover, when sepsis had once developed, nearly 50 per cent. of such empyema cases died, despite rib resection and drainage. Those who did not die were dangerously ill and the object of much anxiety for many days, while their final convalescence was through a protracted illness which left many of the men too crippled for the resumption of full military duty.

Sepsis.—The first task was to ensure the promptest recognition of the development of complicating sepsis in a hæmothorax, for delay in its recognition and in treatment by efficient drainage greatly increased the mortality. Many of these cases were at first erroneously diagnosed, the change for the worse in the patient's condition being ascribed to a pneumonia, or even to renewed hæmorrhage or to the development of a pneumothorax, when in reality the infection had led to an increasing effusion of fluid or to the formation of gas by the action of anaërobic bacilli. Such a wrong diagnosis meant that the patient was kept quiet and disturbed as little as possible, when he very soon died.

A series of autopsies made at the Boulogne base by Captain H. Henry in 1914 and 1915, showed that in all these cases death was due solely to sepsis, and that hæmorrhage hardly ever continued after the first day. At the same time Henry made an accurate bacteriological study of the various organisms met with in infected hæmothorax fluids, showing that the serious infections were caused chiefly by streptococci and anaërobic bacilli introduced from without by the missile and by fragments of clothing.

These observations led to a routine of the earliest possible exploration of the pleural cavity by a needle whenever a patient was failing to recover from a chest wound as rapidly as he should normally do. If a stinking or purulent fluid was found, that was at once accepted as proof of infection and a rib was resected. Otherwise the sample of fluid was examined by the microscope for organisms, and if any were found drainage was usually resorted to. A curious difficulty was often met with at this time, namely, that in a patient who clinically presented all the characteristic features of sepsis the fluid obtained on exploration of the hæmothorax might be absolutely sterile, and yet another sample withdrawn a couple of days later be swarming with organisms. This delay in the bacteriological proof of infection was particularly frequent with the anaërobic bacilli. It was due to the fact that the nidus of infection was at first isolated, perhaps by enveloping masses of blood clot, and that the organisms had not yet escaped to grow freely through the hæmothorax fluid at the early time when the body in general was already reacting to toxins absorbed from the infection. For this reason exploratory punctures at different levels of the hæmothorax, or on successive days were necessary in cases of suspected sepsis.

When infection was proved to exist the pleural cavity was drained by rib resection at the lowest advisable level. Nothing beyond this elementary surgery was for a long time attempted. Surgeons were rendered timid by the opinions that they had brought with them to the war from the teaching of civil experience. They feared that a large opening of the pleural cavity, or a second opening for better drainage, might lead to complete collapse of the lung; they hesitated to manipulate the interior of the cavity lest pleural reflexes should suddenly cause death, or handling a wounded lung should restart bleeding. Consequently at the operation for drainage no general cleansing was attempted. The foreign body was removed only if it was very obvious and easily accessible;

splintered bones were neglected; and the masses of septic blood clot were left to come away in the subsequent process of suppuration.

The results were crudely satisfactory, for life was saved in half the septic cases, and in a fair proportion the lung quickly re-expanded, so that convalescence in a few months ended in a complete return to fitness. Often, however, profuse and exhausting suppuration persisted, and the collapsed lung remained bound down beneath a dense fibrous membrane. Various methods were tried with the aim of preventing this collapse of the lung. Suction apparatus was attached to the opening in the chest wall; or repeated aspirations were used for as many days as possible before rib resection became finally necessary. None of these attempts, however, to deal with the problem of the established empyema were really successful; indeed the methods that were used for this purpose even at the end of the war, though an improvement, did not clear away all the difficulties.

Sterile Hæmothorax.—Simultaneously with the recognition of the frequency with which sepsis might develop, roughly in 25 per cent. of the cases of hæmothorax, and of the need to deal with it promptly, came fuller knowledge of the nature of the simple hæmothorax and of its treatment. At first it was argued that the effused blood should be left untouched in the pleural cavity for many days, since its pressure would keep the lung collapsed and arrest any tendency to fresh pulmonary hæmorrhage. It was also taught that because the fluid withdrawn from a hæmothorax appeared to be an unclotted and non-clotting blood, therefore some action of the serous cells lining the pleural cavity had checked the coagulating processes of the effused blood; and this hypothetical condition was adduced as a further reason against removal of the hæmothorax until the lung wound had had full time to clot and scar. Soon, however, it was shown that renewed bleeding did not occur after the aspiration of a hæmothorax on the fourth or fifth day, while the patient's breathing was made much easier by the removal of the fluid; nor did such aspiration ever introduce infection. Finally, in despite of strongly urged theoretical objections, Captain S. R. Armstrong at Bailleul gave the practical proof that slow aspiration even on the first or second day was not attended by fresh bleeding and that it gave the best results of all. During 1915 it became the custom to remove the fluid from all cases of large hæmothorax, and the complete removal was often aided by a temporary replacement

with oxygen or even with simple air introduced through the aspirating needle so that the lung was kept partially collapsed for a few hours longer, and the patient was spared the respiratory discomfort or even acute distress that was sometimes felt if the collapsed lung were allowed to expand too rapidly after removal of the compressing fluid.

The treatment of chest wounds remained stationary at this point until the summer of 1916. The pathology of the wounds and their natural progress either to recovery or to septic complications had now been fully studied by physicians and bacteriologists; but the practical application of this knowledge seemed unable to advance beyond the treatment of a hæmothorax in either the sterile or infected state. All other aspects of the wound in the chest wall and in the lung itself were disregarded, excepting, of course, that it was always the practice at the field ambulance or casualty clearing station to close completely by means of a pad and strapping any open parietal wound through which air was being sucked in and out.

Prophylactic Thoracotomy.—Meantime military surgery had made great advances in the treatment of contaminated flesh wounds. The early practice of wide incisions and the insertion of rubber drainage tubes as a means of outlet for the products of suppuration, which in 1914 were accepted as an almost unavoidable issue of any wound, was changing. Surgeons now opened the abdomen, the cranium, and the great joints of the body with almost as much tranquillity as in the aseptic operations of civil life. Many of the best operators were in the casualty clearing stations which in 1916 were generally equipped with X-ray apparatus, nursing staff, and every facility for good work. So now the occasion called for a fresh endeavour to deal with chest wounds by applying to them the principles that were universally accepted as right for wounds in all other parts of the body—to stop bleeding by early repair of injury, and to prevent sepsis by cleansing the contaminated wound and removing foreign bodies from it. This principle of early cleansing of the wound track and the avoidance of the rubber tube had, however, to be established before the chest could be approached with success, for early operations on the chest followed by drainage would most certainly have yielded worse results than no early surgery at all.

In 1916, Pierre Duval in the French service and several surgeons in the British service, disregarding all theoretical

objections to the operation, put the matter to the plain test of experience and found it perfectly practicable to open the thorax freely, deal with its contents and close the chest again. No special devices were needed for maintenance of the respiration, and the lung expanded rapidly after closure of the chest. This great advance placed the problems of chest surgery on an entirely different plane of thought. The earlier considerations on the nature of hæmothorax and of lung collapse ceased to be relevant. All that was needed now was an accurate understanding of the character of the wounds, and of the paths by which contamination might spread and cause dangerous infection if the prophylactic operations were not soundly planned.

The thoracotomy itself was easy to perform, but at first the after results fell far short of their ideal aim in the entire prevention of an empyema. Ill results naturally occurred if the operation were performed much later than the first twenty-four hours, when septic organisms were beginning to grow vigorously in areas of inflammation beyond the original wound track. But failure often happened even after an operation at an early hour; and it was only by dint of much thought and experience that a technique was mastered which could cleanse both parietal and pulmonary wounds and keep the all-important pleural cavity free from infection.

In the spring of 1917, the chief principles which should guide the judgment in these operations had been established by Colonel Gask and by Colonel H. M. W. Gray, who inspired many of the younger surgeons to familiarize themselves with the difficulties of the work. The routine operation for repair of the diaphragm in abdomino-thoracic wounds was introduced by Major A. L. Lockwood, and he in conjunction with Colonel J. A. Nixon wrote a valuable account of the progressive developments in their treatment of chest wounds at No. 36 Casualty Clearing Station, where they were so stationed as to have the unusual advantage of watching their own cases through to convalescence.

Various papers were soon published recording brilliant results where life had been saved by early operation, and others where straightforward recovery, unmarred by sepsis, was obtained in spite of contaminated and lacerated wounds which under the old conservative ways of treatment would undoubtedly have been followed by the development of serious infection. The practice of operating early on chest wounds of various types spread quickly throughout the

casualty clearing stations and during the three months of August to October 1917, in the third battle of Ypres, the casualty clearing station surgeons operated on 38 per cent. of the patients admitted with chest wounds. Complete returns were collected from about forty casualty clearing stations, and at the same time records were kept at the base hospitals of the subsequent progress of all cases operated on at the front. The general results are shown in Table I, which also includes similarly collected statistics from the base for August to September 1918.

TABLE I.

(The percentages for C.C.S. and for base are each reckoned separately on the total admissions to C.C.S. and base respectively.)

	1916.	1917.		1918.			
		3,520 Cases.		Boulogne, 548 Cases.		Rouen, 1,309 Cases (5 Special Hospitals).	
Total Mortality—Front and Base	per cent. 30 (estimated)	per cent. 27		per cent. –		per cent. –	
Early Operations at C.C.S.	Nil.	38		about 20		33·6	
Deaths at C.C.S. (at least one-half from shock, etc., rest from sepsis) ..	–	After op. at C.C.S. 24	No op. at C.C.S. 13	After op. at C.C.S. –	No. op. at C.C.S. –	After op. at C.C.S. –	No. op. at C.C.S. –
Deaths at Base (all from sepsis)	6	6·2	–	5·0	5·3	6·2	5·4
Empyemata at Base (including deaths) ..	15	19	–	13	8·9	25·8	15·6

These broad figures show that deaths were a little reduced by early operations, and that subsequent empyemata were also diminished slightly in number. But many empyemata did develop, despite the prophylactic operations, and it is manifest that the general application of the new surgical principles throughout the armies did not improve the results in mass for chest wounds so much as was desired. In judging the results shown by these tables, it must be remembered that during the period covered by them the surgery was often done by men who were unused to thoracic work. In no other branch of war surgery is the technique of the operation more exacting if success is to be ensured, although the manipulations themselves do not require any exceptional dexterity. The apparent ease of the work tempted many surgeons to undertake these operations before they had acquired the special knowledge that was needed to yield good results.

Table II gives the detailed results of primary operations at the front as seen subsequently at the base. The percentages for the base are reckoned on total survivors admitted to the base after operations at the casualty clearing stations.

TABLE II.

Boulogne and Rouen.	Repair of Thoracic Wall.			Prophylactic Thoracotomy.		
	% Deaths at C.C.S.	% Deaths at Base.	% Empyemata at Base.	% Deaths at C.C.S.	% Deaths at Base.	% Empyemata at Base.
1917 ..	9·0	3·5	15·5	18·5	6·0	26·0
1918 ..	?	5·9	17·9	?	6·8	28·2

These figures show that with the average skill available among military surgeons, nearly 30 per cent. of thoracotomy cases developed sepsis later and had to be drained for empyema. Before the practice of early prophylactic operations, the proportion in which sepsis used to develop in hæmothorax cases who survived to reach the base was about 25 per cent. Even after making allowance for the fact that these early operations often succeeded in keeping alive men who otherwise would have died at an early date before reaching the base, these general results are disappointing when judged by the hopes that rested on the perfectly clear advantages of early operation as proved by certain skilled surgeons. Lives were undoubtedly being saved in every casualty clearing station by those who operated, but for lack of proper training in the details necessary for surgical success and of experienced knowledge of the fit occasion for operating, the work of the average surgeon was such that no conspicuous improvement appeared in general statistics.

Two conclusions emerged from this evidence. First, that surgeons required training in the special principles of dealing with chest wounds, and secondly, that only a moderate proportion, perhaps 25 per cent., of cases of gunshot wounds of the chest needed surgical treatment in the first forty-eight hours. The principles that should guide surgeons in their choice of cases needing operation were laid down, so far as knowledge had advanced up to the summer of 1917, in the following general memorandum, issued by the D.G.M.S.

British Armies in France. It was drawn up after a meeting of consulting surgeons and physicians on 25th July 1917 and communicated as a guide to all medical units.

"*Memorandum on the Surgical Treatment of Wounds of the Chest.*

"The recent attention paid to the treatment of wounds of the chest has resulted in a large number of operations, and it seems desirable to indicate the types of cases in which experience has shown that surgical procedure is indicated. It is considered that for the time being all routine operations should be confined to the following :—

(1) An open pneumothorax should be temporarily closed by suture at the earliest opportunity, either at the field ambulance or at the casualty clearing station. If for any reason suturing is impossible, the wound should be packed and strapped so as to render it air-tight.

(2) Extensive parietal wounds, including the above, should be treated as any other large wound. The operation should include the removal of comminuted rib fragments.

(3) Where a foreign body is retained, and careful X-ray localization shows it to be accessible and of large size (not a small fragment or bullet), it may be removed, and the parietes closed after evacuation of the hæmothorax.

(4) Aspiration should be done in the case of any large hæmothorax associated with persistent respiratory distress. This is best done after the lapse of about forty-eight hours.

(5) Gross infections of the pleural cavity should be treated by rib resection and drainage. Where the infection is mild, it is justifiable to resect, thoroughly cleanse the cavity and close the pleura and parietes, as secondary drainage can easily be established later if necessary.

(6) Set operations, for removal of foreign bodies, etc., should not be performed until the initial collapse has passed off.

(7) Whenever the thorax is opened for operation, the opportunity should be taken to close any wound of the diaphragm. This is especially important on the left side, in order to prevent subsequent hernia.

(8) Where open operations have been performed the cases should be retained for ten days after operation.

(9) Reliable X-ray plant and also immediate access to a bacteriological laboratory are essential to successful chest surgery."

Pathology of Chest Wounds.

The majority of the wound tracks lay on a straight line connecting entry and exit, though with rifle bullets it was not uncommon to see circumferential wounds in which the missile had been deviated along a path around the rib cage without actual penetration of the lungs. Occasionally some very curious paths were observed; for example, a bullet, entering the first intercostal space, curved around the second rib through the lung and escaped by the second space immediately below.

Relationship of Injury to Missile.—Rifle bullets usually made clean through and through wounds, with a small punctured entry like a leech bite, and a slightly larger exit wound. If retained, they usually passed through the soft lung, and were found either in the pleural cavity or embedded

in other more resistant structures. They rarely carried obvious portions of clothing into the chest. Sometimes a detachment of part of the outer casing of the bullet, or in other cases an exaggeration of the wobble of the bullet around its axis of spin was associated with considerable laceration of the tissues, and a large exit wound of an " explosive " type. And occasionally in tangential wounds of the chest wall by bullets, the ribs were severely comminuted so that the superficial wound was of a very extensive and gaping character.

Fragments of high explosive shell, bomb and other missiles, being irregular in shape and travelling at a lower velocity without any perforating spin, tended to carry in fragments of clothing and were more often retained. These wounds were attended by greater laceration and bruising of the soft tissues, though sometimes the rifle bullet caused more severe comminution of bone. The shrapnel ball, though smooth, caused wounds somewhat similar to those from shell fragments. Its smashing power was marked, and it was usually retained owing to its low velocity.

Wounds by bayonet or lance were so few in number that there are no data of interest in respect to them.

Grave septic contamination of wounds was in the majority of cases introduced from without, and not by leakage of organisms from the lacerated respiratory tract. It was more frequent in shell wounds, but none the less quite common in wounds by rifle bullets. A moderate proportion of the cases of septic empyema was caused by the introduction of organisms through a gaping wound, as air and blood were sucked in and out of the pleural cavity through it, and this progressive contamination depended simply on the size of the parietal wound orifice, which was often as large with an " explosive " rifle bullet as with a shell fragment. But apart from this form of infection, rifle bullet wounds, whether through and through or simply penetrating, were associated so often with the development of sepsis in a hæmothorax that they could not be set aside by the surgeon as being presumably innocuous. Whatever the missile had been, if there was much evidence on physical examination of the patient to suggest that the tissues of the thorax had been severely lacerated, the probability was that sepsis would develop within the pleural cavity.

The relative fatality of wounds by shell fragments and by rifle bullet respectively has been noted above. In respect of the development of intrapleural sepsis the subjoined figures

are quoted, with the reservation that for through and through wounds the statement of the patient was the chief evidence upon which the nature of the missile could be ascertained.

Elliott and Henry recorded in fifty-three consecutive autopsies at the base in 1914 and 1915 in deaths from septic complications of gunshot wounds of the chest, 21 bullet wounds, five being retained, and 32 shell wounds, 25 being retained. Therefore, of these fatal cases 23, or rather less than half, were through and through wounds.

In 631 consecutive cases at a casualty clearing station Mann noted that septic empyemata were not more common with retained missiles than with through and through wounds and that fragments of high explosive missiles showed only a slightly greater tendency to produce septic changes than did rifle bullets. 70 per cent. of the entire total of his cases had foreign bodies retained in the chest wall or the lungs. Out of the total with foreign body retained (10 per cent. bullet, 90 per cent. shell) 16 per cent. developed septic hæmothorax at the casualty clearing station (11 per cent. bullet, 89 per cent. shell).

Out of the total with foreign body not retained (39·5 per cent. bullet, 60·5 per cent. shell) 21 per cent. developed septic hæmothorax at the casualty clearing station (20 per cent. bullet, 80 per cent. shell).

Gask and Wilkinson gave an analysis of 290 cases at a casualty clearing station, which also illustrate the greater mortality for through and through wounds by shell fragments but they did not discuss the incidence of sepsis. Table III shows these figures.

TABLE III.

Nature of Wound.	No. of Cases.	C.C.S. Mortality, per cent.
Bullet through and through	62	9·7
Bullet retained	12	16·6
Shell through and through	19	47·3
Shell retained	158	20·9
Shrapnel ball	11	9·1
Multiple shell wounds	28	21·4

Elliott, in a total of 453 hæmothorax cases from the Boulogne base in the autumn of 1918, of which 98 had already been operated on at the casualty clearing station, recorded the following figures :—

TABLE IV.

Nature of Wound.	No. of Cases.	Total Cases.	Percentage Septic.	
Bullet through and through	123	190	9·0	7·9
Bullet retained	67		6·0	
Shell through and through	26	147	11·5	15·6
Shell retained	121		16·6	
Uncertain through and through ..	71	116	12·6	13·0
Uncertain retained	45		13·4	

It is clear from these figures that rifle-bullet wounds were frequently associated with the development of sepsis, and that through and through wounds, whether from bullet or shell, were also prone to this complication. The statistics in fact add nothing to the impression formed by the individual experience of surgeons, namely, that it was the character of the wound which should be considered rather than the nature of the missile which had caused it.

Injuries of Bones of the Chest Wall.—Bullets and small fragments of metal sometimes passed through the intercostal spaces, but more frequently the bones were damaged. Clean perforation and simple notching of the rib were rare. As a rule the rib was completely divided and the ends of the fragments severely splintered. These fragments lacerated the pleura and small spicules were frequently carried deeply into the substance of the lung, while the exit wound was often filled with a shower of splinters caused by the missile striking a rib as it passed out. Occasionally bone splinters were driven reversely into the lung by back splash. With the advent of general sepsis these bony splinters necrosed rapidly.

The primary fracture of a rib, due to the direct blow of a missile, was at times complicated by secondary fracture at some distance from the original injury. The secondary fracture was less frequently associated with splintering, but the pleura was often torn by displacement of the fractured rib.

Costal cartilage showed rather less tendency to splintering than did the ribs. Injuries to the sternum were rarely seen in hospital, presumably because such wounds were associated with immediately fatal injuries to the heart or big vessels.

Injuries of the scapula, with splintering, were common. In themselves they were not dangerous, but owing to the mechanical difficulty of excising lacerated muscle under the scapula, sepsis of the pleural cavity was a common sequel.

Wounds of the chest complicated by injury of the vertebral column formed a considerable proportion; they were very serious if the spinal cord was injured. It was, however, common to find missiles lodged in the vertebræ without any physical signs of injury to the cord. These missiles were

Fig. 1.—Drawing of back of left chest which had been torn open by a fragment of shell passing from above downwards. The scapula, S=its spine, was partly denuded of its coverings and lies split in two at the bottom of the gaping septic wound. There was no direct opening into the pleural cavity.

difficult of access. Cases of bilateral hæmothorax were sometimes caused by a missile that had passed through a vertebra, raking the chest from side to side.

Injuries of Soft Parts of the Chest Wall.—These varied from small punctured wounds to large open lacerations

Usually the damage done to the subcutaneous tissues and muscles of the chest wall was very much greater than appeared on the surface, and if the track of a missile was slit up it was seen that the muscle was torn, pulped and infiltrated with blood.

Fig. 2.—From the same case as Fig. 1, illustrating indirect fracture of ribs. Radiogram of chest wall after removal of the lungs *post mortem*. D.F. shows the direct fracture of each rib from 3 to 9 in a line immediately underlying the wide gap in the shadow of the scapula, which corresponds to the split shown in Fig. 1. Ribs 3 and 4 on this line have suffered a slight downward displacement of their fragments along the direction of the blow by the main mass of shell casing. A fragment of metal has travelled sideways and caused a separate comminuted fracture by direct impact on rib 7, where the intercostal nerve was displaced but not torn. I.F. marks the indirect fracture of ribs 2, 4, 5, 6, 8, and 9, at a point close to their angles, with displacement forwards and inwards to the middle line of the outer fragments of ribs 4, 5 and 6. Each of these ends had penetrated the pleura.

Sometimes an escape of air from the torn lung into the superficial tissues around the parietal wound caused a subcutaneous emphysema which varied in degree from a slight local crackling to a distension of the covering even of the

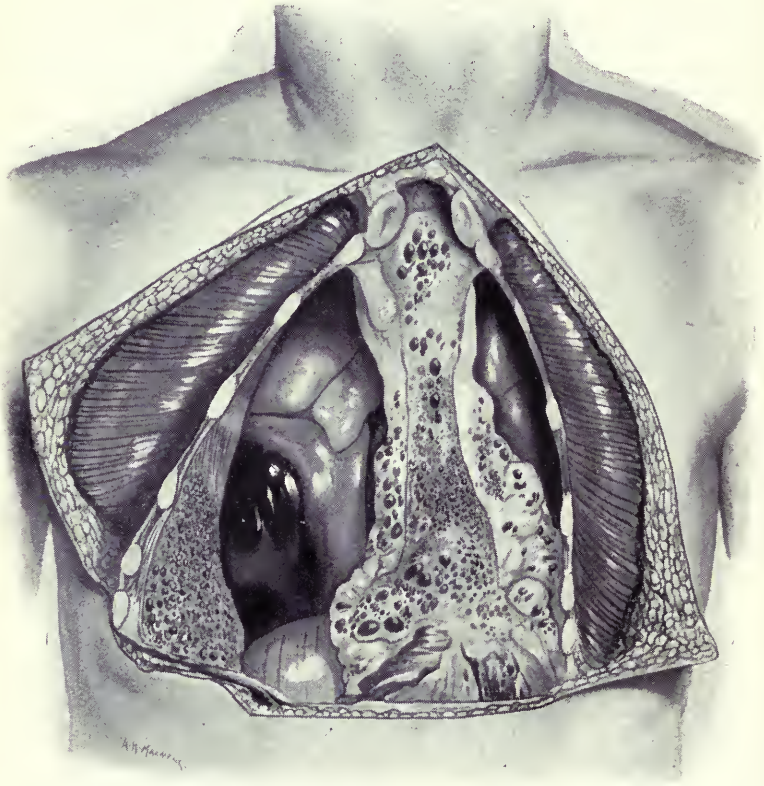


Fig. 3.—Drawing of thorax at autopsy. There is extensive emphysema in the mediastinal tissue behind the sternum and also over the right parietal pleura. The patient died six hours after a non-penetrating dorsal wound of the chest from a piece of shell which passed from the right 10th rib behind to escape over the angle of the left scapula. The right lower lobe of the lung was severely bruised both in front and behind and a drawing of it is shown separately in Plate X.

entire trunk. It was usually quite harmless, and of course lacked the associated inflammatory changes of gaseous cellulitis by anaërobic infection, which was actually rare in the chest wall. This subcutaneous emphysema was commonest when the lung was attached by old pleural adhesions to the

parietal wall, and consequently it was not often associated with hæmothorax. But sometimes it was caused by air leakage, not directly into the tissues of the parietal wound, but along the lung surface into the mediastinal tissues at its root and so up to the neck. (Fig. 3.)

Parietal wounds without penetration of the cavity of the chest were common. It was not always easy to diagnose a penetrating from a non-penetrating wound, for it has been abundantly proved that the bruise from a non-penetrating wound does often give rise to hæmoptysis and may even produce hæmothorax and all the signs which accompany penetration. When penetration occurred, the injury to the pleural membrane might vary from a small puncture or laceration to an extensive defect several inches across.

The intercostal and internal mammary arteries were very commonly torn, and no doubt contributed considerably to the loss of blood suffered by the patient. According to the nature of the wound they sometimes bled externally and sometimes into the pleural cavity. In the formation of a hæmothorax it is impossible to gauge the proportion of blood derived from these sources and the proportion from the wounded lung. Usually hæmorrhage from these vessels ceased spontaneously, but it was quite common during the course of an early operation to find an open and bleeding vessel. It has also been shown that in some cases death from loss of blood resulted from an untied intercostal or internal mammary artery. Secondary hæmorrhage of alarming extent from these vessels has been seen in septic wounds.

The intercostal nerves were doubtless often torn when ribs were broken, but the injury did not present itself as being of clinical importance.

Occasionally a posterior root ganglion was directly injured or indirectly damaged by being torn out of its place. The clinical evidence of this was a traumatic herpes zoster over the entire area of the corresponding segment of skin, either thoracic or abdominal. The skin became slightly sore, reddened and rough with closely set projections which soon assumed a slightly vesicular character, like that of a sudaminal eruption. The change was quite unlike the scattered pustules of the ordinary herpes zoster of civil experience.

Injury to the Lungs.—As in the soft parts, so in the lung, a missile might cause every degree of injury from a small punctured wound to extensive laceration. Even the cleanest and narrowest tracks were accompanied by extravasation

of blood into the surrounding lung, but the lung tissue never showed the radiate fissuring which was often caused in more solid organs such as the liver or kidney. Hæmorrhagic extravasation by contrecoup in distant parts or in the opposite lung was rare.

Fig. 4.—Radiogram of same lung as in Plate IX. To show extent of hæmorrhagic extravasation in a dark area that is really much wider than appears in the surface drawing. The right side in the X-ray corresponds to the left side of the drawing.

Lung with typical bullet wound that caused death in 20 hours. The bullet passed through both lobes and a slight laceration is seen where it crossed the interlobar fissure. Hæmorrhagic extravasation over a wide area around the wound track is evident in the purplish-red tint and greater solidity of that part of the lung.

A missile passing through the edge of the lung might tear a furrow or cut a slit. An irregular missile travelling with low velocity through the lung left in its path a ragged

Fig. 5.—Radiogram of a lung lobe with a gaping marginal wound from a piece of shell; there is extensive hæmorrhagic extravasation around the wound.

cavity filled with clot, and perhaps containing splinters of rib and portions of clothing. Around the track the lung was widely infiltrated with blood, forming an airless mass which could be seen as a shadow under the X-rays. This hæmorrhage, like that of a pulmonary infarct, often presented itself as a raised hæmatoma on the lung surface; or the bruised tissue might protrude like a purple mushroom from the exit wound on the lung. The extreme changes that might be produced in the appearance of the lung surface are illustrated in Plate X,

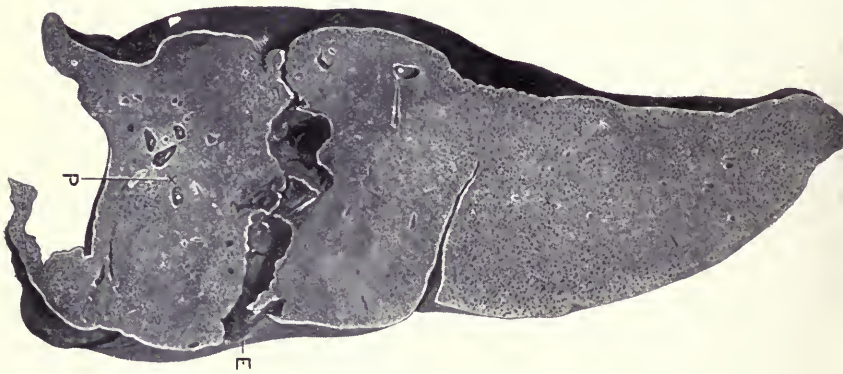


Fig. 6.—Lacerated and septic wound track through a lung made by a shell fragment about ½-in. in diameter. The necrotic blood-clot had been washed out. There is hæmorrhagic extravasation around the track together with the changes of septic broncho-pneumonia.

where rib splinters have been driven into the lung and caused the escape of air in bullous swellings beneath the visceral pleura.

It was rarely that an actual hernia of the lung into a gaping parietal wound was seen, for in such wounds the lung usually fell away to some extent, though never entirely from the chest wall. Hernia, when it occurred, did not lead to strangulation or sloughing of the lung.

Pneumothorax.—Air was liable to enter the pleural cavity from the injured lung or from the wound in the chest wall. Small intrapleural accumulations were very frequent in the first day or two, but they were absorbed rapidly and harmlessly in a few days and could rarely be detected by simple physical examination. Sometimes the air leak was so free that the lung collapsed entirely under the increased intrathoracic pressure, and such a complete pneumothorax might exist, when a large bronchus had been wounded, without any

Posterior view of lung with hæmorrhagic extravasation and a wound in its lower lobe caused by indriven rib fragments, one of which remains in the lung. The upper lobe is also bruised, and on its surface is a large subpleural bleb of air that had escaped from the torn pulmonary tissue. From same case as Fig. 3, the injury having been caused by a non-penetrating tangential shell wound.

appreciable hæmothorax. It was a curious fact that the lung did not collapse completely against the vertebral column when the pneumothorax was caused by free entrance of air from without through a parietal wound.

In a few rare instances of valve-pneumothorax, the accidental anatomy of the wound, whether in the chest wall or in the lungs, caused a valve-like opening into the pleural cavity, so that air was easily admitted, but not expelled with the alternate phases of respiration. In these cases the rapidly increasing pressure of the pneumothorax gave rise to intense and growing dyspnœa which required prompt relief by aspiration or thoracotomy.

Hæmothorax.—This was almost invariably present when there was a penetrating lung wound, though the amount of blood effused into the pleural cavity might be small. This opinion is based, as in the similar question of pneumothorax, on the experience gained from early thoracotomies on a large number of patients in many of whom, before operation, no evidence of hæmothorax could be detected by the ordinary methods of auscultation and percussion. The bleeding might have come from the wounded lung or from an artery in the thoracic wall; and it was often caused by violent tearing or bruising of the lung when the pleura had not been penetrated by the missile, or still more characteristically, when the chest was crushed by severe injuries received from burial by a shell burst.

Spontaneous arrest of hæmorrhage was the rule, and bleeding from the lung at any rate, did not continue for more than twelve hours after admission to hospital. Moreover, opening the chest and manipulating the lung did not cause fresh bleeding.

The effused blood usually gravitated to the back and lower part of the chest cavity, where its extra volume caused compression of the lungs and a collapse that tended to arrest further pulmonary hæmorrhage. When the lung was prevented from leaving the chest wall by the adhesions of previous pleurisy, a hæmothorax was unable to form, or it was confined to a limited area and might even appear high in the chest. In a few of such instances prolonged bleeding from the uncollapsed lung was observed. (Fig. 7.)

Clotting of the effused blood took place with a little delay. If a chest was opened a few hours after injury, the blood was usually found to be still fluid although it coagulated quickly when transferred to a basin. If the chest was not opened

until the second or third day, then the usual experience was to find soft clot in the paravertebral recess and much fluid non-clotting blood in the rest of the cavity, while that part of the lung which was submerged beneath the hæmothorax

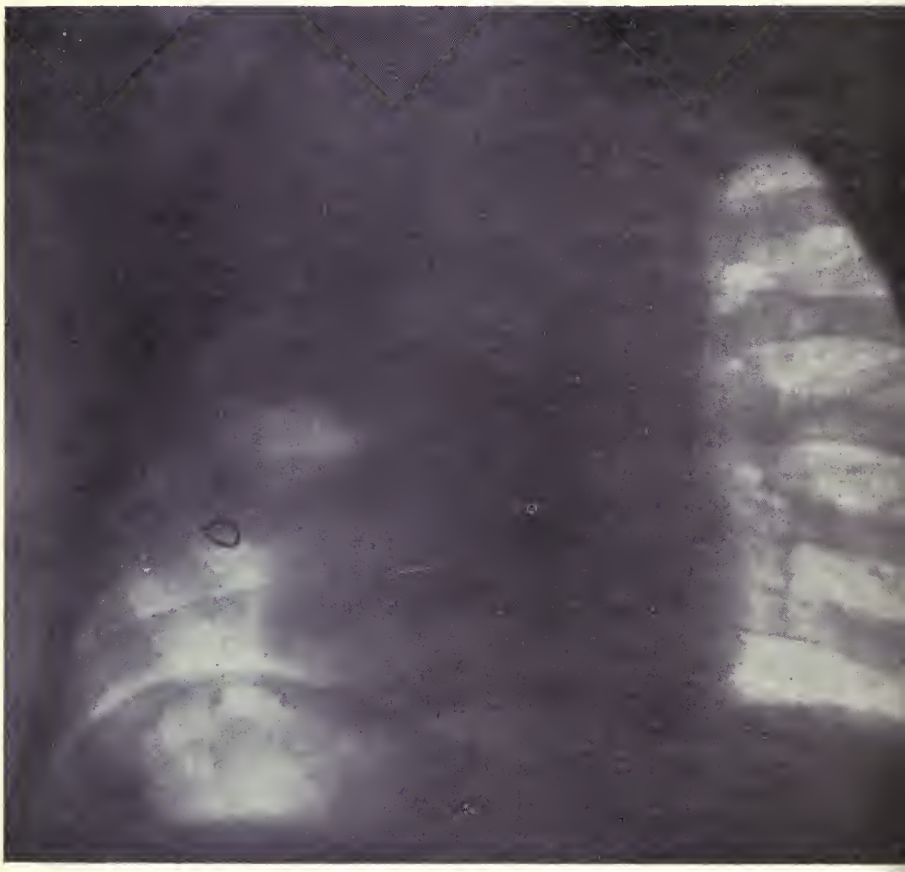


Fig. 7.—Radiogram of high localized hæmothorax at left apex, a rare condition and probably due to old pleural adhesions. The diagnosis was proved by aspiration of the blood. The diaphragm on the side of the hæmothorax is in a characteristically high position. The wire ring marks the position of the nipple.

was lightly coated with a regular deposit of fibrin. It was rare for a massive clot of the whole hæmothorax to occur, because the respiratory movements in the chest churned the blood to and fro and partially " whipped " the fibrin out of it.

Injuries of the Thoracic Duct.—Wounds through the

main structures of the mediastinum were usually fatal at once, and consequently there were few instances in hospital of injuries to the thoracic duct in its infra-cervical course. Some, however, have been recorded, and they require brief consideration, not on account of any practical problems of surgical repair, but because the leaking chyle was a possible cause of confusion in diagnosis. The chyle might clot in big yellow masses, or it might be mingled with blood and give the latter a creamy-red appearance very like that of a purulent hæmothorax. Such cases have been resected and drained in the erroneous belief that pleural suppuration had developed. The opening in the duct might close spontaneously, while in other cases the leakage continued until the patient died of exhaustion.

Wounds of the Diaphragm. — Careful examination either at operations or post mortem proved that wounds of the diaphragm were much more frequent than was at first suspected. The wound might be a small puncture or a long slit, and injury of the abdominal viscera might or might not be associated with it. Sometimes on the right side, bile escaped from the lacerated liver into the pleural cavity, or out through the parietal wound, but this led to no untoward complications and was not provocative of sepsis. On the left side the stomach was often injured, and occasionally this was followed by the development of a traumatic gastric ulcer, which might lead to a late hæmatemesis or even to a perforation connecting the stomach with the pleural cavity. But all these accidents were rare. The chief immediate reason for considering wounds of the diaphragm was that they indicated the probability of serious damage and of sepsis beyond the chest in organs of the abdominal cavity.

Hernia of the omentum or other abdominal contents into the thorax was occasionally seen as an early complication of a diaphragmatic wound ; it has also been recorded as a very late result on the left side when a wound in the diaphragm had been left without surgical repair, and the progressive stretching of the weakened area slowly allowed the stomach and, perhaps, other organs to be forced up through it. The War Office Pathological Collection contains a specimen of congenital diaphragmatic hernia in which a stomach that lay in the pleural cavity was wounded by a shell fragment, and the patient died in a few days from septic leakage that could probably have been checked had the condition been revealed by an early thoracotomy.

Physiological Reactions.—These were the main anatomical features of chest wounds, other than those which relate to the heart, arteries and great veins, and are described in subsequent chapters. As to the physiological reactions which injuries of the chest excite in the patient there is very little definite knowledge, though the material for such an enquiry was so abundant.

A man shot through the lungs might feel very little pain or disability and be able to walk or run a considerable distance afterwards. But usually sharp pain was felt, presumably from the parietal injury, and there was simultaneously great difficulty in the breathing. A severe wound with great hæmorrhage led commonly to severe shock. In cases of less bleeding there was a little shock, but there was considerable difficulty in the respiration and the circulation. The breathing was rapid and shallow ; there was frequent coughing, generally with hæmoptysis, and moderate cyanosis. The cyanosis was not simply due to lung compression by escape of blood and air into the pleural cavity. It was greatest at first, when the lung was mainly pushed aside and not collapsed, and it lessened quickly after the first day, even though a very large hæmothorax might be present.

A wound of the lung was apparently followed by considerable reflex changes in the tone of the main respiratory muscles. The diaphragm on the injured side became immobile and apparently relaxed, so that it rose almost always to a very high level within the chest, at which it often remained despite the weight of superincumbent hæmothorax, and this high position often led to difficulties in the drainage of the pleural cavity. The thoracic, and often, too, the flat abdominal muscles passed into a persistent state of moderate contraction so that, as Sir John Bradford pointed out, the chest appeared smaller and contracted even on the side of a considerable hæmothorax.

Perhaps the bronchial musculature was also excited to a general reflex constriction, which interfered with the tidal current of air throughout all the lung. Of this no proof was obtained, but it has been surmised theoretically that these two conditions, contraction of the thoracic muscles and constriction of the bronchioles, would unite to lessen the volume of the lung, interfere with respiration, and produce a general state in which whole lobes of the lung on either side might ultimately become quite airless and pass into the condition which Colonel W. Pasteur first described in civil experience as that of " massive collapse."

The general condition of cyanosis and difficult breathing tended to pass away after a varying number of hours, when the patient, so to speak, got his "second wind." But it was the experience of surgeons that extensive thoracic operations were much more serious if undertaken before this final state of readjustment had been established. As the hæmothorax settled down and the lung beneath it completely collapsed, giving a flat resistent note on percussion, the patient became less and not more cyanosed. Presumably some vascular adjustment was made, similar to that in areas of extensive lobar pneumonia, and the pulmonary circulation, though not that by the bronchial arteries, was closed down throughout the collapsed lung, with a corresponding engorgement and vascular congestion of the opposite lung, especially in its base.

The free air in the pleural cavity, unless large in amount, was absorbed in a day or two; and the lung above the hæmothorax came again into close contact with the chest wall. But this upper part of the lung then generally passed into a state of extreme relaxation, and for several days gave the Skodaic signs of compensatory emphysema with such exaggeration as occasionally to mislead observers into thinking that pneumothorax was still present. The margins of the hæmothorax below this emphysematous area of lung were quickly sealed off by light pleural adhesions; but the collapse of the lung below continued to increase for a little time under the pressure of an augmenting volume of fluid.

The pleura reacted to the escaped blood by a mild inflammation. Serous fluid, often in considerable quantity, was added by effusion to the original hæmothorax; with this were large endothelial phagocytic cells, other leucocytes, and often so much inflammatory fibrinogen that the whole fluid, if withdrawn by aspiration on a later date, might show marked secondary clotting, just like that of an ordinary pleural effusion. This inflammatory reaction often proceeded to actual fibrin formation within the interior of the chest, and the surface of the collapsed lung, even in the absence of sepsis, might become coated with a very dense jacket of deposited fibrin that greatly hindered expansion later on when the fluid had been absorbed.

Normal Repair without Sepsis.—This took place when contamination of the wound was absent, and in the majority of cases of hæmothorax a straightforward recovery was observed. The wounds in the soft parts healed rapidly: hæmoptysis soon ceased, and the injured lung was quickly restored to

normal with a surprisingly small scar. Small foreign bodies retained in the lung caused as a rule no subsequent trouble.

The re-expansion of a lung that had been collapsed by compression was also rapid. A complete pneumothorax would vanish altogether in three or four weeks. The fluid from a moderate sized hæmothorax, of 30 or 40 ozs., was absorbed in the course of two or three months and left no evidence of lung compression. But occasionally, and much more frequently in the instances of large hæmothorax, the lung failed to expand satisfactorily, and in consequence the chest wall progressively fell in and became flattened on the side where the effusion had existed.

Fig. 8 is from a case of shell wound by small fragment, passing through first intercostal space and resting within a vertebra after perforating lung apex. Death occurred on seventeenth day from operation for arterio-venous aneurysm. The hæmothorax had filled the left pleural cavity and the lung was uniformly collapsed beneath it. After removal of the lung from the body the blood-clot was easily peeled away from its surface, leaving a smooth pleura. A band of the fibrinous jacket was left in position and the lung was then inflated through the trachea by bellows. It rapidly expanded where the clot had been removed, but elsewhere remained imprisoned and unexpanded.

Aspiration of the fluid was very rarely followed by any fresh accumulation ; and it certainly aided re-expansion of the lung in the larger effusions, if done before the fibrin jacket had formed in crippling density around a lung in the state of extreme collapse.

Changes associated with the Development of Sepsis.—The whole picture changed when contamination of the wound introduced sepsis into the pleural cavity. Sepsis confined to the parietal wall or to the lung was of a much less serious character. It has already been pointed out that sepsis, chiefly as an empyema, was the cause of practically all the deaths that occurred after the first forty-eight hours.

The ways in which the pleural cavity might be infected were various.

The missile and portions of clothing or skin carried with it might introduce organisms directly into the pleural cavity.

A sucking wound with a free opening from the outside into the pleural cavity, through which air and blood passed in and out, always led to secondary infection from the skin or clothing unless promptly closed.

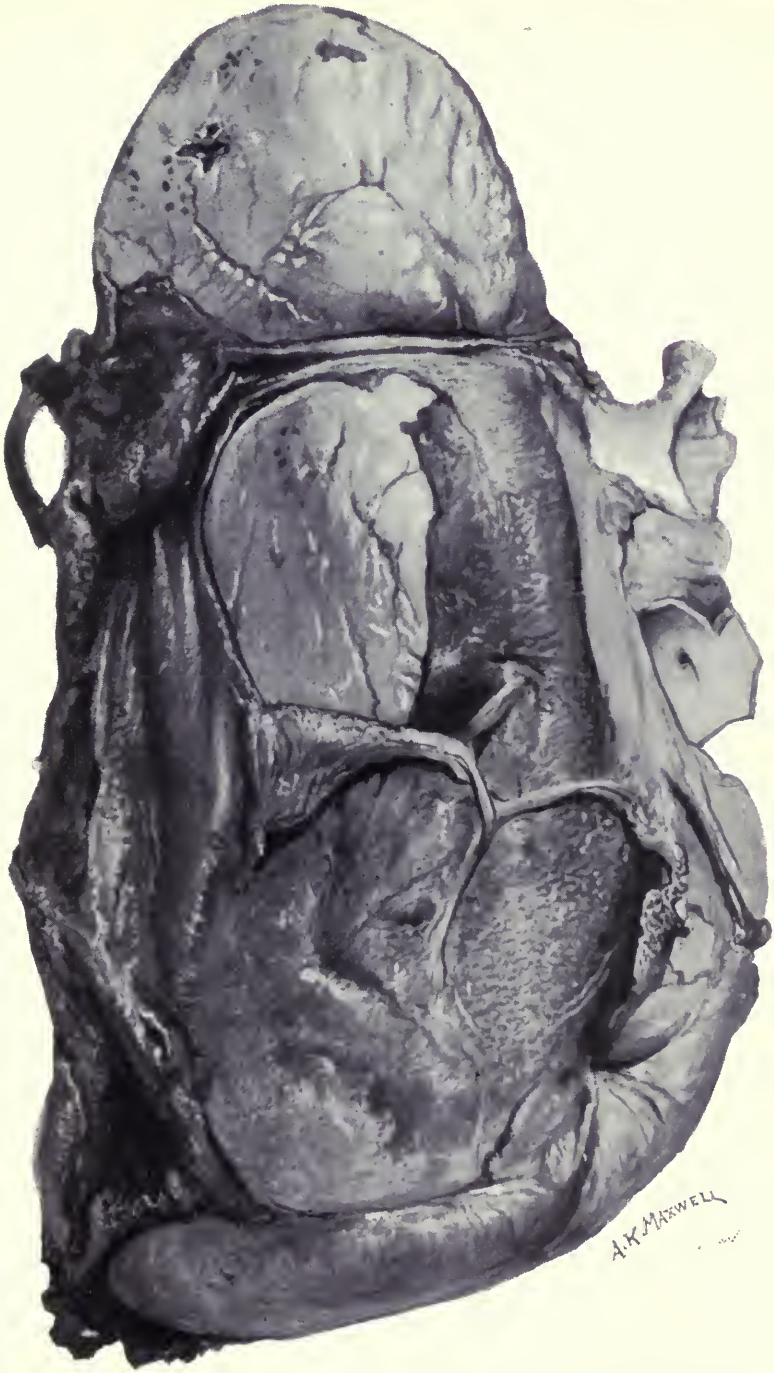


Fig. 8.—Lung from a late case of sterile hæmothorax, illustrating the way in which the deposit of fibrin and blood-clot hinders re-expansion.

The wound in the chest wall, especially when muscles were badly lacerated and there was much bony splintering, often became the seat of septic processes which in their turn entered into and infected the pleural cavity.

A lacerated track through the lung was liable to cause delayed infection of the pleural cavity in the same way as an infected parietal wound. Such infection was usually by external organisms carried with the missile into the lung, but occasionally it came from the resident flora of the torn respiratory passages.

Infection from the abdomen by organisms escaping from injured abdominal viscera was relatively rare.

Infection of the Thoracic Wall.—At the time when the practice of surgical cleansing of a parietal wound was not generally observed, superficial chest wounds were constantly seen in a state of moderate suppuration. But apart from the fear that this might extend deeply and cause an empyema, there was little anxiety felt about such suppuration, which generally maintained a local character in the chest wall itself and did not necessitate the wide precautionary incisions that had to be used for wounds in the fleshy masses of the limbs

Streptococcal and anaërobic infections were both common, especially in wounds of the scapular region where the thickness of the muscular layer and their inaccessibility to surgical cleansing rendered them of greater severity. A wound which on the surface seemed to be healing cleanly often hid a deep infection that might at any time spread inwards through rents in the pleura. And since all the wounds were potentially contaminated, it was dangerous to enter a sterile pleural cavity through the neighbourhood of the original wound on any day later than the second after the injury, when the implanted organisms might have become more virulent.

Infection of the ribs and necrosis were not frequently seen, but long-standing sinuses were sometimes the result of small sequestra ; and splintered separate fragments in the presence of suppuration readily became necrotic.

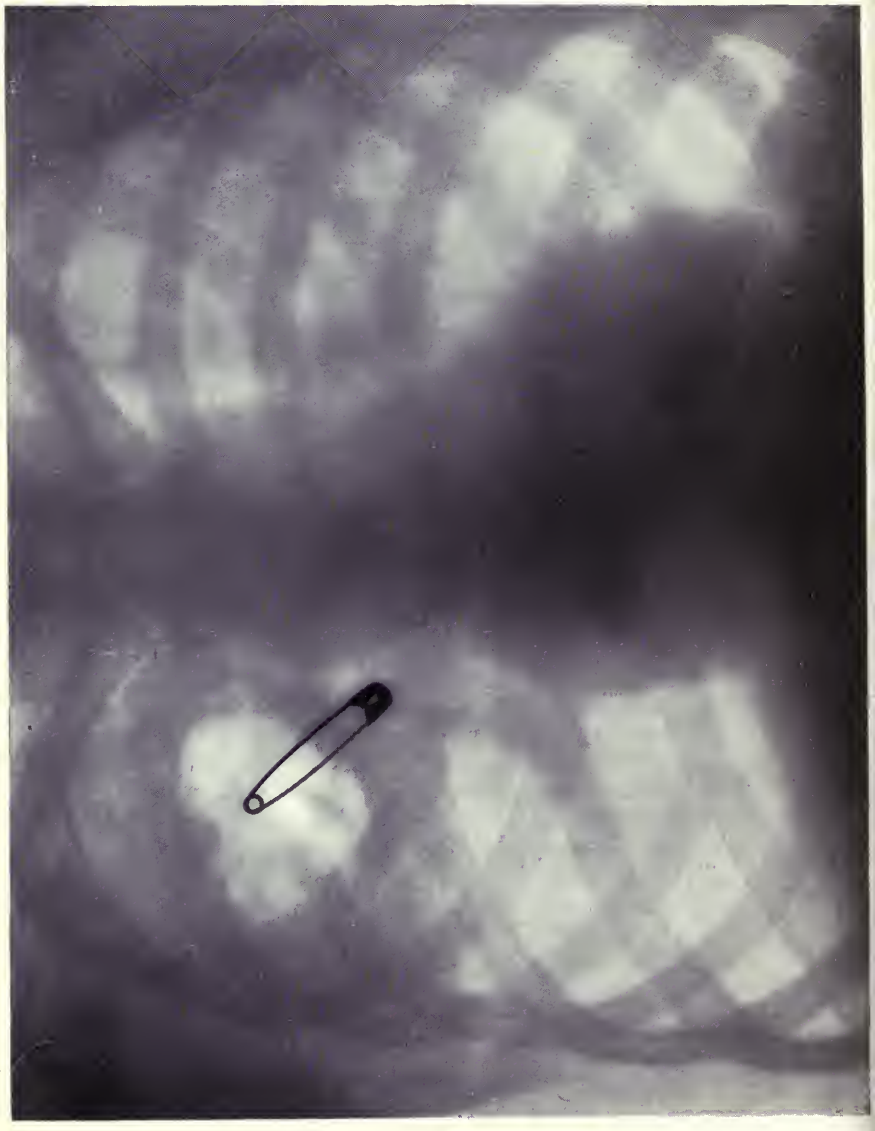
Infection of the Lung.—Lung tissue was very resistant to the spread of wound infection. Bacteriological examination of material taken from a lacerated track through the lung or from around an embedded missile often revealed the presence of anaërobic bacilli, yet gaseous gangrene of the lung was most uncommon and so, too, was a local abscess. Nor did the injury to the lung often start the inflammation of ordinary pneumonia or broncho-pneumonia, though the weakening of the

patient by loss of blood, by exposure after his wound, or by the development of general wound-sepsis occasionally resulted in a complicating purulent bronchitis or broncho-pneumonia of a serious nature. Laceration of the lung tissue, even when the wound track had developed infection, soon gave way to healthy processes of repair. The infection did not spread through the lung and the injured area usually showed a very limited necrosis, provided that some path could be found for escape of the infected matter. Unfortunately the easiest path was through the surface of the lung into the pleural cavity; and it is very probable that many of the cases that were clinically septic, but in which proof of infection of the hæmothorax was obtained only after some days' delay, were examples in which the pleural cavity was infected by a backward growth of anaërobic bacilli or other organisms from a contaminated lung wound through overlying blood-clot, and so ultimately into the fluid of the pleural cavity.

When the empyema was drained these lacerated tracks appeared able to heal without the development of chronic fistulæ, and it was very rarely that sloughing processes spread through the lung and caused danger from secondary hæmorrhage. The quick repair of lacerated and infected lung tissue, provided that adequate drainage be given, is well illustrated in the skiagram. (Fig. 9.)

Bronchial fistula rarely persisted in a chronic form. Cases in which the contents of an infected hæmothorax were being coughed out through some opening into the bronchi healed without any trouble as soon as the empyema was emptied by operation. Large openings from a torn bronchus into the pleural cavity were not often seen. An outward puff of air from an external wound on coughing was not in itself sufficient proof of the existence of a suspected fistula, for this puff was often produced simply from the pleural cavity by the intake of air with the inspiration preceding the cough. Such suction and expiration were very misleading in wounds under the scapula. The majority of bronchial fistulæ, that were clearly proved to exist, healed spontaneously in a few months.

Broncho-pneumonic changes of a septic type on the side of the injury were commonest when the lung had been contused and lacerated by bony splinters but where hæmothorax had not formed. The collapse of the lung under a hæmothorax and the arrest of its air current seemed to help it greatly in resistance to all infective processes; and it was a common experience at an autopsy to find the lung on the opposite side



1st April, 1915: Bullet wound through apex of right lung; entrance through second right space in front and exit behind external to hilum. No hæmoptysis.

3rd Day: Exit wound enlarged. No hæmothorax.

10th Day: Bronchial fistula and free suppuration from posterior wound. X-ray taken, showing a hole blown clean through the lung and surrounding density due to hæmorrhage and inflammation.

10th Week: Discharged fit from hospital with fistula healed.

4½ Months: Passed for return to full duty in France.

and also that part above the hæmothorax widely infected by purulent bronchitis or scattered broncho-pneumonia, while the lung beneath the hæmothorax had altogether escaped these inflammatory changes. But on the other hand, accelerated expansion of this area of collapsed lung by early aspiration or by thoracotomy with removal of clot did not cause it to become unduly susceptible to such secondary infections.

Infection of the Pleural Cavity.—The ways in which this may occur have already been classified. Experience showed clearly that the pleural membranes are able to withstand and deal with a very considerable amount of infection, but it was none the less necessary to assume always that infected cases were liable to form empyemata. The empyemata were divided into two classes, those with and those without hæmothorax. The latter were relatively uncommon, but they were the more dangerous. They were chiefly due to streptococcal infections growing in from a lacerated parietal wound, or to pneumococci, from the damaged lung. The fluid in the streptococcal cases was thin, of a turbid yellow colour and very slightly purulent; these cases were very fatal. Pneumococcal cases without hæmothorax were sometimes seen in which the inflammatory mass was so densely coagulated that no fluid could be withdrawn by the needle, and yet the heart was displaced for a couple of inches by the exudate. But pneumococcal effusions generally contained ordinary thick pus.

A hæmothorax is an excellent breeding place for organisms, although it is probable that the latter grow more freely at first in the clot than in the pool of fluid where they may be exposed to some inhibiting action of protective substances. The fibrin deposited over the pleural surfaces slows down the absorption of toxin from an infected hæmothorax, and for this reason the patient may in the beginning show comparatively slight illness even in the presence of a heavy infection. If the pleural membrane is examined early in the case of a severely septic hæmothorax, evidence of infection may be recognized by petechial hæmorrhages or by an increased deposit of inflammatory fibrin over the pleura.

The organisms found infecting a hæmothorax in France were chiefly anaërobic bacilli, streptococci and staphylococci introduced from without by soiled skin or shreds of clothing. Rather less than 20 per cent. contained pneumococci, or Pfeiffer's *B. influenzæ*, that had escaped from the respiratory tract. Henry found in 101 consecutive cases of septic hæmothorax, examined from the third day onwards, the following infections.

Organisms found.	No. of Cases.	Total Deaths.
Pneumococcus, *B. influenzæ*, and *M. tetragenus* —that is, from respiratory tract	17	4
Streptococcus and Staphylococcus	38	11
Anaërobic gas bacilli (23 alone, 19 with other organisms)	42	14
Diphtheroid bacillus, *B. coli*, etc.	4	0
	101	29

Infections with *B. influenzæ*, *M. tetragenus*, and *B. coli* were very mild, though associated with free formation of pus; the fluid with *B. coli* was quite odourless. The streptococcal infections were most serious of all. Those by anaërobic bacilli were at first very fatal because their novel character often caused them to be overlooked; but when the signs indicative of their development were properly recognized and the empyema treated without loss of time there was good hope of recovery. Such infection by anaërobic bacilli was very common, occurring in more than a third of all infected cases, either alone or in association with other organisms. The anaërobes, in the commingled form in which they usually appeared, produced gas, hydrogen and carbon dioxide from the glucose in the blood, and malodorous bodies together with sulphuretted hydrogen by a simultaneous proteolysis. The effused blood was quickly hæmolysed and to the foul-smelling mixture was added a rapid exudate of pus from the pleura. The amount of gas produced was variable, but it was sometimes very great and not of necessity malodorous. Its volume caused great increase of the intra-thoracic pressure, up to a positive reading of 15 or 20 c.c. water, and a comparatively rapid displacement of the heart.

The typical evidences of anaërobic infection of a hæmothorax were a progressive increase in the fluid effusion, the development of a small loculated or of a large general pneumothorax above the fluid, and constitutional indications of sepsis. An ingravescent jaundice, if present, could be regarded as almost pathognomonic. The pleural fluid, when removed for examination, was deeply hæmolysed, generally stinking and turbid with pus. If unrelieved by evacuation of the pleural cavity, the patient died either of general intoxication or from the mechanical pressure of the gas in the pleura.

In these, as in all other forms of empyema, there was a great tendency for dry pleurisy to appear at the base of the opposite lung by some spread of infection. But actual empyema seldom, if ever, developed on the opposite side, and the pleural friction vanished when the hæmothorax was drained. Repeated aspirations alone might suffice to enable a patient to overcome a small infection, even with anaërobes, when there was no great mass of clot in the chest. But as a rule the thorax had to be opened and the interior cleansed, sometimes with immediate closure, but more frequently with subsequent drainage.

Pericarditis, even apart from direct injury to the pericardium, was not uncommon as an early complication of septic hæmothorax. It was then a manifestation of general blood infection by streptococci and was usually fatal within two or three days. Anaërobic bacilli did not spread into the pericardial sac from the pleura.

The mortality of empyema was always high—on the average nearly 50 per cent. despite drainage—though with skilled care it could be reduced to 20 per cent. But when once the patient had survived the first two or three weeks of severe sepsis, recovery was usually rapid. The lung expanded fairly well, and the sinus closed in three or four months, though there was usually some flattening of the affected side of the chest. Late complications were very rare. No case of cerebral abscess following thoracic wounds and their empyemata was recorded from France or England.

Foreign bodies retained in the lung in septic cases did occasionally lead to abscess formation, with secondary hæmorrhage or fresh empyema at a later stage.

Septic Hæmothorax.—Infection may spread virulently through the hæmothorax within twenty-four hours of the wound ; in other cases it may be present and yet give rise to no clinical features for days ; or again there may be clinical evidence of sepsis at a time when at any rate the fluid of the hæmothorax is innocent of infection, though a day or two later it is teeming with organisms.

Infection occurred in about 25 per cent. of the hæmothorax cases in Flanders, and it was almost always fatal if not treated surgically. The closest attention to patients with hæmothorax was necessary in order that no precious time should be wasted by delay in detecting the features indicative of spreading infection. Some officers made a rule of needling every hæmothorax case daily for the first four or five days,

and examining the fluid microscopically for organisms. This perhaps was hardly necessary, if the general condition of the patient was carefully watched for clinical evidence of sepsis. Any suspicious features, however, should at once compel an exploratory needling and examination of the fluid withdrawn.

The general clinical features of infection may be classified under three main headings. Those produced by the general toxic action on the patient of substances absorbed from a septic area, which may be in the lacerated lung, in the blood-clot, or in the free hæmothorax fluid; those caused by inflammation in the pleural cavity; and certain special physical signs within the chest. The first two groups may be caused by any infecting bacteria, but the special physical signs of the third group belong to infection by gas-producing anaërobic bacilli.

When sepsis is present the patient does not mend, and day by day each feature of uneasiness increases. Sleep is broken and uncertain; the appetite fails, he complains of pain and tenderness in the affected side of the chest, and the breathing becomes more dyspnœic; the cheeks may develop a brilliant hectic flush, and an obvious icteric tint appear in the conjunctivæ. Together with these changes the face assumes a slightly anxious expression. Restlessness amounting to actual light delirium, by day as well as by night, is noted in the most serious infections. The temperature is always raised, but sometimes to so slight a degree that on this count alone it would appear idle to suspect sepsis. Indeed, the temperature is apt to be a most misleading guide if too exclusive reliance is placed upon it in searching for evidence of infection. Increase of the pulse-rate is of greater importance. Tachycardia above 110 is rarely seen with a simple hæmothorax in a patient who is free from other complications. The development of jaundice should be looked for with the closest attention. A sterile hæmothorax may cause a slight conjunctival icterus, but nothing more. Real jaundice, especially if associated with epistaxis, is always an index of a particularly severe type of infection by anaërobes either alone or with streptococci; and not an hour should be lost in dealing with the patient when once this yellow tint has appeared.

The pleural inflammation within the chest on the side of the hæmothorax is shown by an increase in the size of the effusion and by local tenderness and pain. In most cases this pain is mild and needs inquiry to reveal it; but in a few it produces continual distress, and may even lead to a referred tenderness

over the hypochondrium with rigidity suggesting abdominal injury. At the base of the opposite lung a coarse pleurisy often develops from spread of the infection across the chest, and its recognition should always emphasize the need for exploration of the hæmothorax.

Pericarditis develops in a small proportion of these infections, and is usually fatal before the effusion has attained a large size. But friction sounds heard over the cardiac area are not in themselves to be interpreted as being of invariably bad prognosis. They may be caused by a dry pericarditis, which slowly disappears in the same way as does the dry contralateral pleurisy; or they may simply be the trivial and transitory sounds that are occasionally produced from leakage of air from the lung into the mediastinal tissues.

The special physical signs on the side of the hæmothorax are simply those caused by the development of gas within it. This gas may be loculated within the hæmothorax, or it may collect freely above the fluid in the pleural sac. In the latter case the signs are indistinguishable from those of an ordinary pneumothorax; but the gas is formed so abundantly that the heart suffers continually greater displacement. An example of the general pneumothorax type is well illustrated by the following case:—

Wound of right chest by rifle grenade. 5th June, 1915.

7th Day: Moved to base hospital. Dyspnœa increased rapidly in the train, and the patient arrived almost pulseless.

8th Day: Very ill, but perfectly conscious. Slight cyanosis. Body bathed in icy cold sweat. Tongue clean, but tremulous. Temperature 100°, pulse 132, respirations 40. Heart displaced 2½ ins. to left and signs of large pneumothorax with bell sound on right. Except for the toxic sweat, the patient's condition was exactly what would have been expected from a supposed leak of air and blood caused by the journey.

Explored: Foul gas and dark purple blood, which was teeming with *B. sporogenes*. Intercostal drainage at once, since the patient was too collapsed to endure a fuller operation.

10th Day: Rib resected.

24th Day: Recovered well. No secondary fever. Heart back to normal position, but right lung still much collapsed. Patient discharged to light duty at end of three months.

The loculated collection of gas is almost in itself a diagnostic feature. Percussion reveals a resonant area, often with a low pitched note that is almost "cracked pot" in character, within the boundaries of the area of dullness that demarcate the hæmothorax. The gas producing the note is usually loculated at the back, somewhere near the angle of the scapula. Whenever this peculiar percussion note is met with at a level above that of a possibly high diaphragm, that is the ninth rib, and the cardiac displacement seems unusually great in

Fig. 11.—X-ray of same chest as Fig. 10, but with patient lying flat. The fluid is no longer obvious, and it is now possible to see the boundaries of the cavity in which the fluid and air were collected. The lung had been wounded forty days previously by a revolver bullet. The hæmothorax had slowly become infected with Pfeiffer's *Bacillus influenzæ* leaking from the lacerated track in the lung, and was being coughed up from some fistulous opening into the bronchus. All healed quickly after rib resection and drainage.

proportion to the area of dullness, gas infection should be suspected and tested for by exploration at the lower limit of the resonant area.

It is needless to discuss the differential diagnosis from pneumonia or other chest complications that might cause fever and general distress in a patient. The physical signs often fail to make the diagnosis secure. Safety is gained by discarding these dubious distinctions, and by reliance on the exploring needle.

In difficult cases an X-ray examination of the chest by the fluoroscopic screen with the patient in a sitting posture will often lead to the solution of the problem. When mobile gas and fluid are present in the pleural cavity the fluid will appear as a dark pool with an upper horizontal level. The surface of the free fluid shows oscillations caused by the heart-beat, and will be violently agitated if the patient coughs. Its level changes in relation to the chest wall when the patient is tilted first to one side and then to the other. Such an appearance is diagnostic of a collection of free fluid below gas or air. (Figs. 10 and 11.)

Diagnosis depends on a great readiness to suspect sepsis and on prompt exploratory puncture. If the results of the exploration do not give evidence of sepsis, it is sometimes justifiable to act upon the clinical opinion alone and adopt the surgical treatment for established infection.

Proof of sepsis in the fluid withdrawn by exploration is given by any of the following characters: An offensive odour with a purplish-red hæmolysed blood, caused by anaërobic bacilli, a turbidity in the fluid, whether this be blood or serum, from which a deposit of reddish-brown or creamy-yellow pus is thrown down on standing in a test-tube—chyle leaking from the thoracic duct, as already noted, in rare cases may give an opaqueness like that of pus, but it does not fall to the bottom on standing—microscopic identification of organisms in films from the centrifugalized fluid.

It is not necessary to make cultures of a doubtful fluid in order to discover possible organisms a day or two later, for the most rapid incubation is in the chest itself, while the culture of the sample is always liable to be falsified by skin contaminations. If a case is clinically suspicious but the bacteriological report negative, a second and third exploration should be made on the following days, and at different levels in the chest, for the pleural contents at the commencement of infection are often not homogeneous.

Henry has given the subjoined list of the more common organisms found in infected hæmothorax fluids. These vary in virulence; but the need for prompt surgical treatment should be based on the clinical aspect of the patient rather than on the type of organism found.

Cocci.
- Gram-negative:
  - *Micrococcus catarrhalis.*
- Gram-positive:
  - (1) Streptococci.
  - (2) Staphylococci.
  - (3) Pneumococcus.
  - (4) *Micrococcus tetragenus.*
  - (5) Sarcinæ.

Bacilli.
- Gram-negative:
  - (1) *B. coli* and coliform organisms including *B. proteus* and *B. pneumoniæ.*
  - (2) *B. pyocyaneus.*
  - (3) *B. influenzæ.*
- Gram-positive:
  - (*a*) Aërobic—
    - (1) *Subtilis-mycoides* group.
    - (2) A diphtheroid bacillus.
  - (*b*) Anaërobic—
    - (1) *B. perfringens.*
    - (2) *B. sporogenes.*
    - (3) *B. von Hibler IX* and others.
    - (4) A small diphtheroid.

Physical Signs and Symptoms.

Hæmoptysis occurs in most cases of injury to the chest; it it is alarming to the patient but not often serious. It generally ceases in three or four days. Hæmoptysis is by no means an infallible sign of penetration of the chest. It has been demonstrated time and time again that a wound of the parietes without penetration of the pleural cavity may be associated with hæmoptysis, and even with hæmothorax.

Great pain is a factor that sometimes induces a surgeon to operate early. This pain may be due to indriven splinters of ribs scratching the parietal pleura at each respiratory movement.

Dyspnœa and cyanosis are among the most prominent and characteristic signs of a severe wound of the chest. The breathing is usually rapid, shallow and often painful, while the patient is very conscious of the difficulty of "getting his breath." Immediately on receipt of the wound these features are often marked, and if the one lung is put out of action the *commotio thoracis* is great and may be fatal. Dyspnœa is increased by exertion, emotion or movement; hence on arrival at hospital after a journey the patient was put to bed and allowed to rest for an hour, if this was possible, before a physical examination.

Hæmothorax is the most common result of a penetrating wound. If small (5 to 10 ozs.), it cannot be detected by physical signs. If the hæmothorax is a large one (20–50 ozs.), the symptoms presented are those of dyspnœa, usually a marked feature of the first two or three days. The physical signs are those of fluid in the chest; but in the first twenty-four hours they are of an unusual character, because the presence of some pneumothorax and also the incomplete collapse of the lung beneath the hæmothorax tend to delay the manifestation of the dull percussion note that is later associated with fluid and a completely collapsed lung. The heart is considerably displaced away from the hæmothorax, and this sign is the most important of all. The breath sounds are at first weak, and later become tubular or lost in accordance with the ultimate state of collapse reached by the lung. In the early stages the upper level of dullness on percussion may shift between the sitting and lying down position, presumably because a small pneumothorax is associated with the hæmothorax. The movements of the affected side are restricted, and the diaphragm is immobile or nearly so, as proved by X-ray examination, and often abnormally high. This high position may be suggested by the discovery of an unusually high position of the stomach resonance on physical examination. The heart is not displaced upwards so much as might have been expected from the position of the diaphragm, and its chief displacement is lateral.

In most cases of penetrating wounds a certain amount of air is found in the pleural cavity; this is in ordinary cases quickly absorbed and is not demonstrable except upon opening the chest. If the pneumothorax is a large one the clinical picture is similar to that of a hæmothorax, but the dyspnœa may be more marked. The displacement of the heart is greater, the percussion note elicited above the level of the fluid is very resonant and the breath sounds, together with the vocal resonance in this area, are weak or absent. If the coin or bell sound can be obtained pneumothorax is certainly present, but its absence does not exclude pneumothorax, for the sign is governed by the pressure of the air in the cavity, and that varies. In some cases of extreme distension the chest actually bulges out, and in the presence of a valve pneumothorax distension increases rapidly together with respiratory distress and progressive displacement of the heart.

Subcutaneous emphysema around the wound or over a considerable area of the chest wall is fairly common, and requires

no special treatment. It is easily recognized by the crackling sensation felt on palpation, while percussion gives an exaggerated tympanitic note greater than that over a pneumothorax. As a rule it occurs in cases where the lung is still adherent to the chest wall, and therefore it is not often seen together with extensive hæmothorax or pneumothorax. But it always gives proof that the lung has been ruptured.

Apart from collapse of the lung caused by the pressure of a pneumothorax or hæmothorax, a curious condition is occasionally met with in which large areas of the lung that were not under pressure have none the less passed into an airless state of "massive collapse." This condition had been first described by Colonel W. Pasteur in civil experience as occurring sometimes in the lower lobe of a lung after an abdominal operation. Instances of it were soon recognized in France by several observers, and in thoracic more frequently than in abdominal wounds. It was most easily recognized when it chanced to occur in a wounded chest where there was no additional hmæothorax to confuse the diagnosis, and here it was perhaps more frequently seen with tangential wounds. The physical signs over the affected area, usually the lower lobe or the middle sector of that lobe, in the main resemble those of hæmothorax, namely, immobility, smallness of the chest, weak or tubular breath sounds, dull percussion note, vocal and tactile fremitus, sometimes increased or sometimes lessened, but the essential diagnostic sign is that the heart is displaced towards, not away from the area of dullness because the total contents of the pleural sac are now smaller than normal. In a few hours, or a few days at the most, all the signs would clear up as the patient was encouraged to breathe freely and to cough, and the heart would then return to its normal position. (Figs. 12 and 13.)

This peculiar massive collapse is more difficult to detect in the presence of a hæmothorax. It occasionally occurs throughout the lower lobe of the opposite lung, but much less frequently than some physicians asserted. Probably too, it may exist on the side of the hæmothorax, though its presence is then difficult to prove since the collapse and the hæmothorax tend to move the heart's apex in opposite directions.

In a few instances it had evidently been caused by the blockage of a bronchus with inhaled blood and mucus. In others the mechanism was obscure. Though the condition is uncommon it is most important for the surgeon to be familiar with its features so that he may avoid dangerous or unnecessary

Fig. 12.—Radiogram showing massive collapse of both lobes of the left lung, from tangential bullet

Fig. 13.—From same case as Fig. 12. X-ray taken ten days later, when physical signs were completely normal again and the heart had returned to its proper position.

operations, for a thoracotomy in the first forty-eight hours on a patient with this airlessness of the opposite lung is almost certain to be at once fatal by its final embarrassment of the respiration. The warning of the presence of this collapse on the uninjured side is given by unusual respiratory distress and cyanosis, and examination shows that these are associated with retraction of the chest and sucking in of its lower intercostal spaces during inspiration on the side opposite to the wound. At a later date a persisting state of massive collapse is liable to be confused with hæmothorax, empyema or pneumonia and to receive treatment designed for these other conditions. The correct diagnosis is easy when attention is paid to the position of the heart.

In the case of complicating wounds a prompt decision is required as to whether the serious condition of the patient is attributable mainly to the chest wounds or not. Nixon gives the rule that if there is fair air entry into the lungs the intra-thoracic injury is not to be held accountable for the symptoms.

Abdominal injury may be obvious from the track of a through and through wound. Failing this X-ray examination may help. Abdominal rigidity and immobility may be caused reflexly by a pure chest injury; but localized tenderness and pain in the abdomen, or hiccough and the catchy breathing suggestive of diaphragmatic injury strongly suggest that the abdomen also has been entered by the missile, and often only careful radiography can show whether or not operation is required.

Spinal injuries are usually shown by paraplegia. Injuries to the vertebral bodies may cause excessive pain which radiates irregularly and is often puzzling.

Cases in which the missile had not passed out of the body were examined by screening with X-rays, which gave valuable information concerning the position and size of the foreign body, the existence and extent of hæmothorax and pneumothorax, the condition of the opposite lung, cardiac displacement, and movements of the diaphragm. An examination with the screen in the lying down position was usually enough, and plates were rarely needed except for a permanent record. Occasionally it was necessary to screen in the sitting up position in order to demonstrate the characteristic horizontal line of a hæmo-pneumothorax.

General Treatment.

The aims of the surgeon are first, to prevent immediate death from shock and hæmorrhage; secondly, to remove all sources

of infection which are a danger to life and a cause of delayed convalescence; and thirdly, to restore as far as possible the normal function of the lung and shorten invalidism. It has been demonstrated unequivocally that the correct treatment of a contaminated wound consists in early complete excision, with removal of all devitalized tissues and foreign bodies, followed by early closure of the wound. It has been proved equally clearly that compared with such mechanical cleaning of a wound the value of any antiseptic whatsoever is insignificant. It is therefore the duty of the surgeon to apply these principles to wounds of the chest, while the administrative service must make the necessary arrangements for the application of these principles, as far as the exigencies of war allow.

The treatment outlined below recapitulates the methods recommended for the use of the medical officers of the British Expeditionary Force in France at the termination of the war. On some points opinion was firm and decided: on others it was divided, and further progress and experience in chest surgery will doubtless lead to a re-casting of some of these views. These methods of treatment require a perfectly organized and equipped medical service, such as that which existed with the relatively stationary warfare on the Western Front, and a quick and easy line of evacuation from front units to hospitals. Difficulties of campaigning may render them in part impracticable, but a knowledge of what ought to be done will enable a surgeon to improve his work even in the worst environment.

Many writers dealing with previous wars have recorded the high mortality of chest wounds and the various methods of treatment then employed. From time to time improvements have been introduced, to be forgotten and rediscovered later, and it will be seen from the following notes from past history that much of the procedure that was finally accepted as right in 1918 had been attempted by surgeons in bygone wars.

There are fair records of the methods used for treating wounds of the chest, as far back as the 14th century. At this period wounds were the result of injuries from arrows, sword, lance or dagger; gunpowder was not in use. The treatment of wounds was confined to salves, ointments, powders and decoctions of herbs, to some of which magic properties were attributed. It was considered that suppuration was the natural sequel of every wound; that a wound

could not heal properly without suppuration, and that if it did not suppurate recourse should be had to suppurative medicaments.

With the 14th century came a bright but brief awakening of intellectual enthusiasm in which surgery shared. About 1260, Theodoric, an Italian surgeon, had commenced to modify the customary suppurative treatment of wounds by a substitution of dressings soaked in wine (that is an antiseptic method). Theodoric had a pupil Maître Henri de Mondéville, a Frenchman, born in Normandy in the latter half of the 13th century. Mondéville instituted a method of treating wounds which is surprisingly modern. He is believed to have been the first to demonstrate that the formation of pus is not necessary in the healing of wounds. He recommended that the large intestine, if wounded, should be sutured "as furriers sew a skin," and replaced in the abdominal cavity. He states that he saw wounds of this sort, when sutured and closed immediately, heal in a short time with a single dressing. For penetrating wounds of the chest, his treatment was to remove all foreign bodies and to close the wound as quickly as possible. For as he says, great danger follows delay if they remain open or gaping. Mondéville is regarded as one of the great surgeons of history. He was well known to his contemporaries and is quoted by his successors. He is often mentioned by John of Arderne, the contemporary English surgeon, who however, does not appear to have appreciated the new doctrine, though as surgeon in the services of John of Gaunt he must have seen much military service.

France possessed another great surgeon during the 14th century in the person of Guy de Chauliac who published his book the *Grande Chirurgie* in 1363. Guy was generally in favour of healing wounds by first intention, but he did not recommend early closure of chests, relying rather on the injection of medicaments into the cavity to dry up the effusion. In the event of inflammation, however, counter incision with a razor for drainage was advised.

Subsequent to this period there was a great decline of learning. With this, surgery also fell away, and the advances made by Mondéville and his contemporaries seem to have been forgotten, or at any rate, they fell into disuse.

The treatment of chest wounds in the 15th and 16th centuries seems to have been very primitive; ointments and salves were applied, and penetrating wounds of the chest were treated by means of tents to keep the hole open and by injections into the pleural cavity.

With the advent of gunpowder, wounds became more severe. The missiles at that time were large and of low velocity, and the wounds must have been ragged and associated often with indriven pieces of clothing. The fact that they were dangerous and provocative of inflammation is indicated by the universal belief among surgeons of the period that gunpowder was venomous and poisoned the flesh. To neutralize this poisonous effect, the practice of the time was to cauterize the wound by injecting boiling oil.

Ambroise Paré published his book on *Wounds by Arquebus* in 1545. He was led in 1556 to abandon the practice of cauterizing wounds by boiling oil, when by accident, he ran short of oil and found that the wounds did as well or even better without it.

In 1563 Felix Wurtz, who started work with a barber of Zurich, published his book in which one finds again the recommendation that chest wounds should be sutured early, though he was not in favour of suturing wounds of other parts.

In the 17th century general surgery was improving fast, but still there was no particular improvement in the treatment of gunshot wounds of the chest in that century, nor in the 18th century; and it is only with the Napoleonic era of the 19th century that any distinct advance is noted.

The two surgeons who have left records of this improvement are Guthrie of the British service and Baron Larrey on the French side.

The wounds of the Peninsular War were almost entirely gunshot wounds, and they were certainly of a severe type owing to the large musket ball used.

Guthrie's treatment is far in advance of any other surgeons noted since the time of Henri de Mondéville. He was quite clear about the danger of inflammation and took all the precautions then known to avoid it. His practice was to remove all foreign bodies, splintered bones and the missile, when accessible. He was also a great advocate of immediate closure of chest wounds by suture, which was common in the Middle Ages, and seems to have been forgotten and re-discovered time and time again. Guthrie also notes that this immediate closure prevented the exit of fluids and this led to a curious practice, which was a forerunner of modern aspiration. He states that " the advantages derived from the closure of such wounds led to the practice of sucking them by the mouths of irregular practitioners, generally the drum major of the

regiment, when the patient was a soldier; and the consequences, in some instances apparently miraculous, were in others quite as unfortunate."

Baron Larrey, the great French surgeon of the period and friend of Napoleon, has left a clear picture of his treatment of the French wounded. In the case of penetrating wounds of the chest with a lodging missile, Larrey's practice was :—

(1) To excise the wounds as far as the fractured ribs.
(2) To extract loose splinters of bone.
(3) To ligature the intercostal vessels if bleeding.
(4) To cut off jagged ends of rib.
(5) To remove the ball if within reach.
(6) To suck out blood and air from the pleural cavity by the application of dry cups to the edges of the wound.
(7) The wound was then sealed by an agglutinative plaster.

He was not clear about making a wide opening into the chest to get at retained foreign bodies, but had evidently thought about it and suggested a method.

The story of the treatment of chest wounds in the Crimean War is melancholy. Much that was known at the beginning of the century seems to have been already forgotten, or else not put into practice. Perhaps the fault lay with the administrative, rather than with the medical service. It is well known that the medical arrangements in the British army in this war were sadly deficient, and good surgery is impossible without the necessary facilities of hospitals and equipment.

Patrick Fraser, physician to the London Hospital, has left some interesting records concerning the high mortality which attended chest wounds. Wound inflammation was held to be the source of great danger, and the common method of combating this was venesection. The chief theme of Fraser's book is the exposure of the futility of venesection as a curative measure.

The wars following the Crimea, namely the American Civil War and the Franco-German War, also demonstrated clearly the great fatality which attended chest wounds. There does not appear to be much to record regarding improved treatment, though many valuable observations were made with regard to morbid anatomy, and venesection was abandoned in these wars.

Before the next great wars occurred, the discoveries of Pasteur and the resulting antiseptic treatment of wounds had caused

a revolution in surgery, and it might have been expected that the treatment of wounds in war would be attended by as great an improvement as with those in civil life.

The records of surgery in the South African War showed clearly that in comparison with previous wars the mortality was low and the wounds were of a less severe type. It is tempting to infer that this was the result of antiseptic surgery, but in reality it was due to the change in character of the missiles and of the wounds inflicted rather than to any improvements in treatment. The old musket, with its large ball that smashed bone and lacerated viscera, had been replaced by a high velocity rifle and a hard-nosed cylindrical bullet. These narrow bullets at long range simply perforated the body, and if no vital spot was hit, often left nothing but a small clean track which healed rapidly without suppuration.

The favourable results of these wounds persuaded surgeons that wounds were often best left alone to heal by natural processes. Injuries of the abdomen and chest were not operated upon. Consequently, experience in the South African War added nothing to our knowledge of the treatment of chest wounds; and indeed, in a sense, it may be said to have been actually a hindrance to progress. The results of the conservative views acquired in that war were that, when the campaign of 1914 opened, surgeons were slow to realize the severer nature of the wounds that were then inflicted, and the policy at that time was to avoid extensive surgical treatment of casualties close to the firing line.

Treatment in Field Ambulances.

It was generally accepted that no serious operation on the chest should be attempted in advanced dressing stations. Treatment was confined to combating shock when present and lessening respiratory distress by closure of an open sucking wound. Patients with severe shock were placed in the most comfortable position, usually the semi-recumbent, restored as far as possible by heat and hot drinks or rectal injections, and given morphia, but not more than half a grain.

During the last year of the war the experiment was tried of sending up to the forward medical units "Shock Teams," equipped with means of giving intravenous injections of gum or of blood. The experiment proved a success, and if the war had continued the practice would probably have been extended.

Wounds opening into the pleural cavity through which air

was drawn on inspiration or blood leaked were closed at once by temporary suture. The relief of respiratory distress was immediate and great; in addition, the likelihood of introduction of bacteria was lessened. The best way of closing these wounds was by a continuous suture passed deeply through the two edges of the wound. This was quickly and easily done without an anæsthetic. It had to be well done so as to prevent air being sucked in as well as blown out, otherwise a positive pressure in the pleura might result (valve pneumothorax). Closure might also be done by plugging the hole with gauze, firmly covered with strapping, but this was not so efficient as suturing.

The patient was evacuated to the casualty clearing station with as little delay as possible, provided that shock or features of serious hæmorrhage were neither present nor developing. It was an advantage to some to travel in the semi-recumbent position.

Treatment in Casualty Clearing Stations.

On arrival, usually six to twelve hours after injury, the patient was put to bed, and if the symptoms of shock were present the necessary means of combating shock were applied.

A survey was made of the whole body and all wounds examined. It should be remembered that injury to the contents of the chest may be caused by missiles entering another part of the body, such as the face, the neck, the shoulder and even the pelvis. Evidence of hæmothorax, pneumothorax or collapse of the lung should be sought for, with particular attention to the displacement of the heart. Much was gained by careful examination of the movements of the chest as a whole, and especially of the amount of air current in and out of the lungs. The body was searched for complicating wounds, particularly with regard to abdominal and spinal injury. The first concern of a surgeon at the front was to come to a quick conclusion as to whether or not the patient should be submitted to immediate operation.

A careful examination of the patient was required to ascertain whether the wound was a penetrating one; if an immediate operation was required to save life by arresting hæmorrhage or by relieving shock; and if an operation was required to avoid sepsis and restore function. A sucking wound that had been closed by temporary suture at the field ambulance almost certainly required operation.

A survey of the whole body having been made, a decision was arrived at as to whether or not the patient should be submitted to immediate operation.

Cases which did not require Primary Operation.—These formed the majority of the cases and included :—

(1) Small clean wounds, especially through and through bullet wounds, without evidence of serious intra-thoracic injury other than hæmothorax.
(2) Cases in which a missile was retained, but was either smooth or only of small size, not exceeding about two centimetres in diameter.
(3) Cases in which a retained missile, though of large size, was in an inaccessible position.
(4) Cases of uninfected hæmothorax of small size. It is not justifiable to open the pleura in such cases merely for the sake of evacuating the blood, for they nearly all recover without interference.

Conditions in which Primary Operation was indicated :—

(1) A ragged wound of the soft parts.
(2) Compound fracture of ribs.
(3) Bleeding from the parietal wound which continued when the wound was uncovered for examination.
(4) Severe pain (often the result of indriven splinters of rib scratching the chest wall with each respiratory movement).
(5) An open wound of the thorax, through which air was pumped in and out of the pleural cavity, a so-called " sucking " wound.
(6) Crushed (" stove-in ") chests with extensive laceration of the lung by displaced bone.
(7) Valve pneumothorax
(8) Large simple hæmothorax in the state of a massive clot.
(9) Acute infected hæmothorax.
(10) Abdomino-thoracic wounds with injury of the diaphragm, especially on the left side.
(11) Retention of a large foreign body.

Conditions in which Primary Operation was contra-indicated :—

(1) Shock and collapse, of such severity as would contra-indicate any surgical operation.
(2) Collapse of the opposite lung, as suggested by intense dyspnœa, cyanosis and respiratory retraction of the chest wall on the contra-lateral side. In this condition the administration of an anæsthetic and the opening of the chest may be immediately fatal.

Immediate Surgical Treatment.—If an operation is to be done, it should be undertaken as soon as possible after the initial shock has passed off, and before sepsis has become established. It was found by experience that operation could usually be undertaken about six hours after admission to a clearing station. After the lapse of forty-eight hours it was rarely advisable to perform any operation, except for evacuation of an infected hæmothorax.

Patients with chest wounds bear operation well, and take a general anæsthetic satisfactorily. It was found unnecessary to use any form of pressure chamber or insufflation apparatus. In the British services chloroform was commonly used in conjunction with oxygen and was given through a " Shipway's " apparatus. Some surgeons preferred local anæsthesia; the French used ether, and the Americans gas and oxygen. It appears, therefore, that the choice of anæsthetic is not very important and may be left to the discretion of the individual operator.

Wounds of the soft parts, unless small and clean, should always be excised even if nothing further is done; otherwise they suppurate and infection is liable to spread along the track of the missile into the pleural cavity.

Excision of the soft parts led the surgeon to the ribs. More often than not the ribs or the scapula were broken, and, whether or not the chest was opened, the splinters of bone should at least be removed, ragged ends of rib cut clearly off and all dead tissue excised. That is to say, the first step in the treatment of a chest wound is to make a careful complete excision of the parietal wound. In some cases this is as far as the surgeon should go.

Excision of the wound allowed a careful examination, which might reveal either a bleeding intercostal artery or a large hole, hitherto unsuspected, leading into the chest. A finger introduced into the pleural cavity might now discover splinters of bone either free or sticking into the lung. Such splinters ought to be removed, for they play a great part in the production and maintenance of sepsis. The case is now converted into one of open pneumothorax. Two courses are then open to the surgeon. He may do what was called the complete operation, opening the chest, repairing the lung, cleansing and closing the pleural cavity; or he may content himself with the parietal excision and suturing, after evacuation of the blood from the pleural cavity by rolling the patient to one side or by aspiration. The decision between the two courses might be

difficult. For a skilled surgeon it should be the rule that if any operation entering the pleural cavity is undertaken for a penetrating wound of the chest, it should be done completely, since the latter method yields in the long run the best results.

A wound over the sternum suggesting an injury of the pericardium does not contra-indicate thoracotomy. If during the course of the operation a tear of the pericardium is noticed, the hole should be closed by suture, and if the missile lies in the pericardial cavity it should be removed.

Bubbles of air leaking from the lung into the anterior mediastinum give rise to curious noises, which when first heard, may suggest pericardial friction, and deter a surgeon

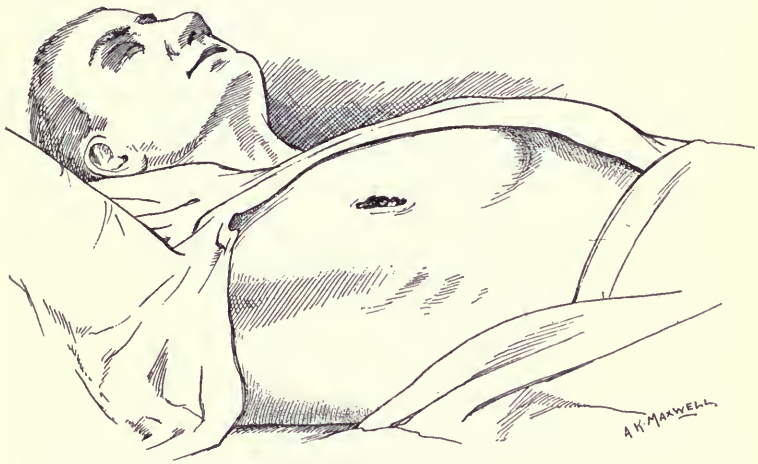


Fig. 14.—Drawing of patient with open wound of right side of chest, through which air was being sucked in and out. The series of drawings Nos. 15–17 show stages in the thoracotomy performed on this patient fifteen hours after infliction of his wound.

from operating. These physical signs vanish on absorption of the air in two or three days, and the condition does not call for any special attention.

Thoracotomy through the Wound.—The first essential is the complete excision of the wound including the skin, muscles and broken ends of rib. This having been completed, the chest should be opened with fresh instruments. An incision is made from the edge of the wound through the skin along the line of the broken rib, either forward or backward, so as to obtain the best access to the cavity of the chest. Then the muscles are incised down to the rib, retracted, and the periosteum incised along the middle line of the exposed

rib. Along this line the periosteum is stripped off with a rugine. A Doyen's periosteal rib elevator is then slipped in and the periosteum entirely separated (Fig. 15). The bone is then cut through with a pair of rib shears or bone forceps and removed. To allow free access to the pleural contents and insertion of the hand, it is necessary to take away 4 ins. of rib. The posterior layer of periosteum or rib with the parietal

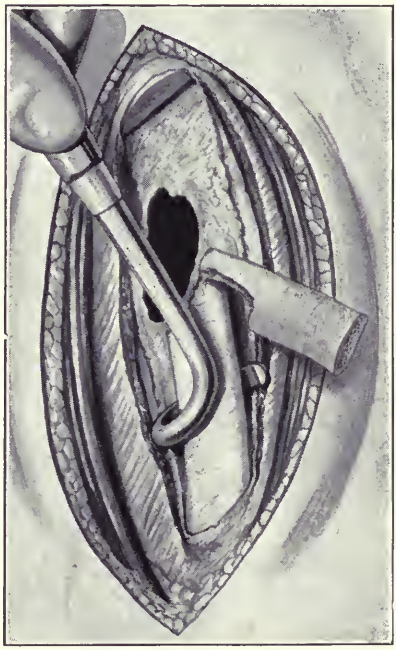


Fig. 15.—The wound of the soft parts has been excised down to the broken rib, which is being lifted subperiosteally by Doyen's elevator; the wound through the parietal pleura is exposed.

pleura attached is next incised with a pair of scissors along the middle of the gap. Then a retractor or rib spreader is inserted and the chest opened widely (Fig. 16).

Thoracotomy by Fresh Incision.—This operation may become necessary when an opening through the wound will not allow access to the injured portion of the lung, for instance, when the wound is in the lower and posterior part of the thorax and the foreign body near the hilum or in the upper lobe of the lung.

Resection of 4 ins. of the fifth or sixth rib in the anterior axillary line gives a good exposure of the thoracic contents, and if there are no other considerations, this is probably

the best and easiest route to follow. It has to be remembered, however, that if drainage of the pleural cavity has to be performed later on, it cannot be done effectively through this incision. Therefore, if the nature of the wound and missile is such as to indicate probable future infection, it may be advisable to choose a lower rib and make the incision

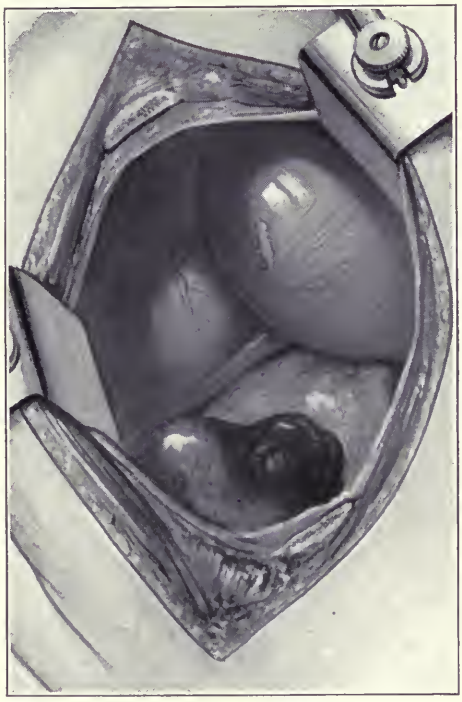


Fig. 16.—The pleura has been incised in the line of the resected rib and the chest opened widely by means of a rib spreader. The effused blood has been evacuated, giving a clear view of the diaphragm in which there is a small injury; of the mediastinum, uninjured; and of the wounded collapsed lung. The hole in the lung and the rent of the diaphragm were sutured; the cause of the injury, a piece of shell, was removed from the pleural cavity, and the chest closed.

more posteriorly. A 6-in. incision is made along the line of the selected rib, and continued down to the periosteum, which is stripped off the anterior surface with a rugine. With a rib elevator and shears 4 ins. of the rib are resected. The posterior layer of periosteum with the parietal pleura attached is then incised along the whole length of the middle of the gap, and the retractor or rib spreader inserted.

The following alternative methods were also used for thoracotomy by fresh incision :—

(1) Incision through an intercostal space, with or without section of one or two costal cartilages, was practised. A good exposure may be obtained by this method, provided the patient is young and has elastic ribs. Post-war practice has tended to show that the intercostal incision is a simpler and better method than excision of a rib when the opening has not to be made through the wound.

(2) As an alternative to the intercostal incision, Cowell suggested that the rib should be split along its longitudinal axis. This method merits trial.

(3) Before the war the pleuro-costal flap method was advocated. This is unnecessary and prolongs the operation.

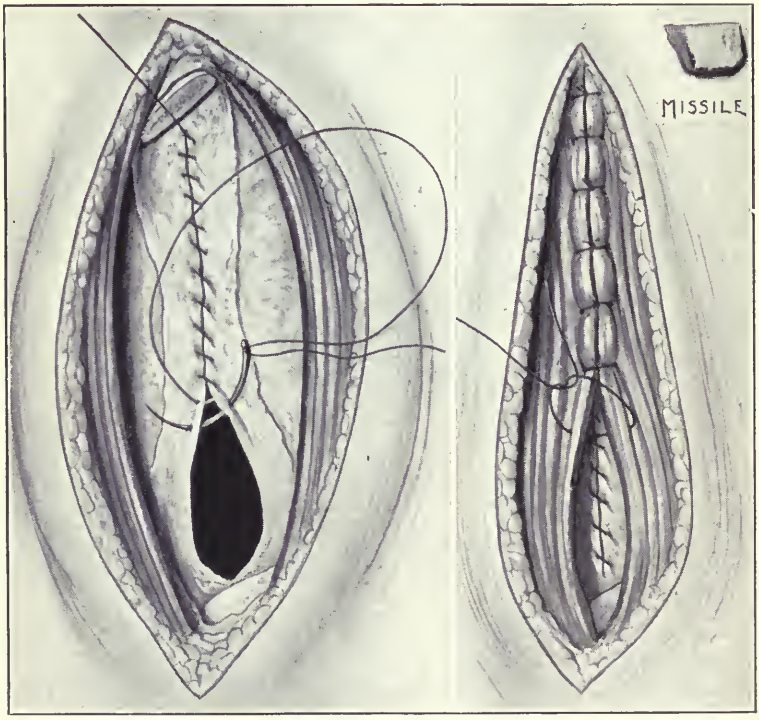


Fig. 17.—Shows the first and second stages of closure of the chest. First the parietal pleura together with the periosteum of the rib is sutured, then the muscles, and finally the skin. The shell fragment that was removed from the chest is shown at the side. The patient made a good recovery without suppuration, and was transferred to England.

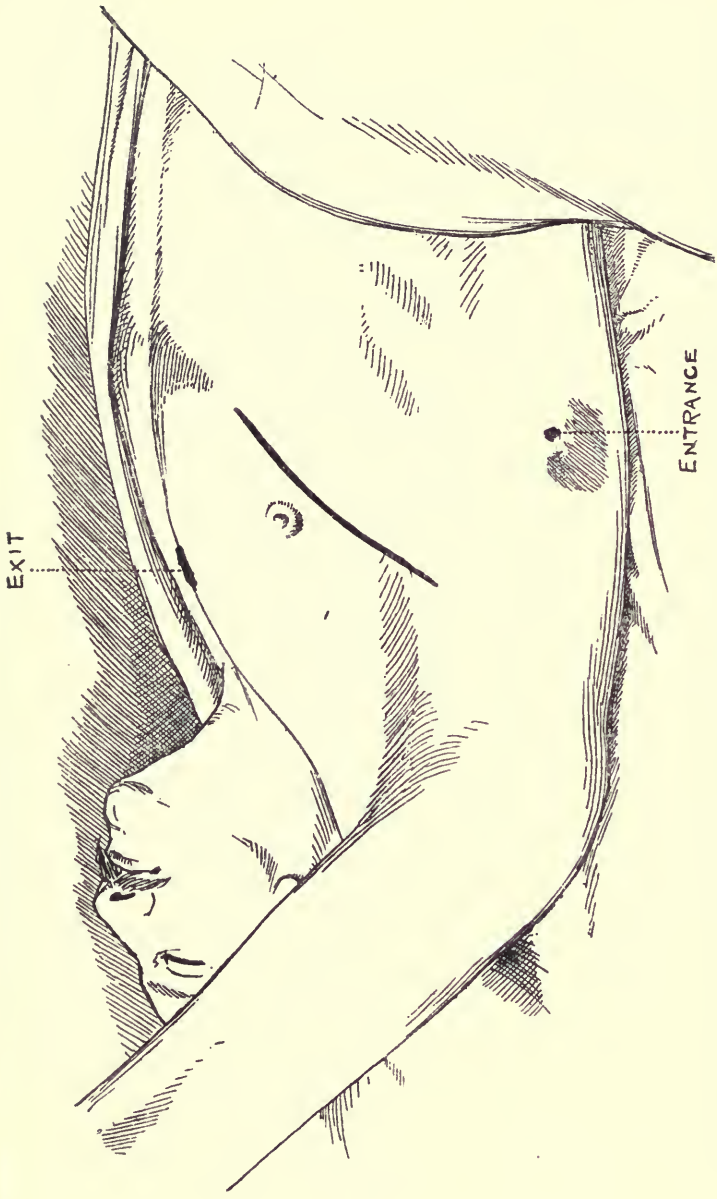


Fig. 18.—Drawing to illustrate thoracotomy by fresh incision between the entry and exit wounds. The patient had been hit by a rifle bullet which perforated the right chest and divided the internal mammary artery. The right pleural cavity was filled with massive clot which could not be aspirated.

Procedure within the Thoracic Cavity.—After the chest has been widely opened, either through the wound or by fresh incision, it is advisable to remove the blood from the pleural cavity, first because it is easier to see what has to be done and, secondly, because removal of the blood relieves respiratory difficulties. The blood can be removed by rolling the patient on to his side. Probably, however, it is better to do it by swabbing with gauze or scooping out the clot with the gloved hand; less disturbance is caused to the patient by this method. This done, the gloved hand should be inserted into the pleural cavity and swept around in order to detect and remove any splinters of bone which may be lying free, or the missile and portions of clothing. These are most likely to be found in the pleuro-diaphragmatic recess. On any occasion during the operation when the hand is not in the pleural cavity the opening should be temporarily closed by a wet compress or other means, so as to help the respiration of the opposite lung by lessening the flapping movements of the mediastinum.

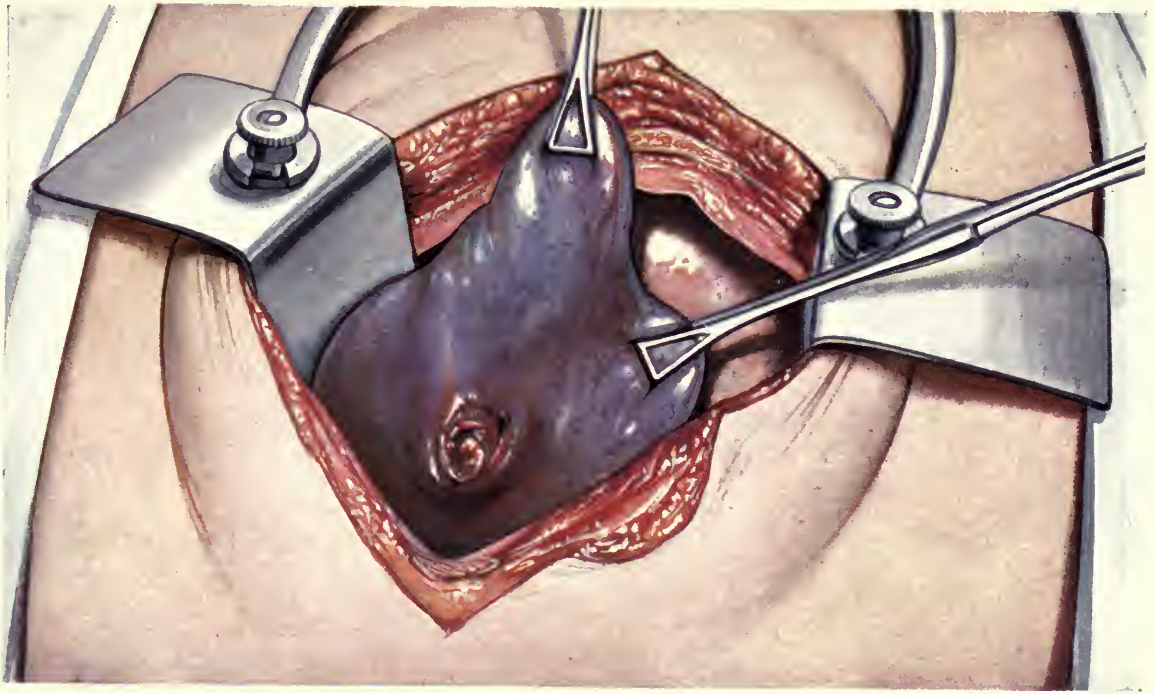
Next, any foreign body retained in the lung may be detected by the fingers, and with the aid of two pairs of lung forceps the affected area is brought into the opening of the chest. The lung can be handled as easily as a coil of intestine, and without causing any reflex fall of blood pressure.

Plate XI illustrates the chest widely opened in operation of thoracotomy performed fourteen hours after reception of wound. The lung, which is collapsed, wounded, and infiltrated with blood, is pulled out by means of Duval's forceps.

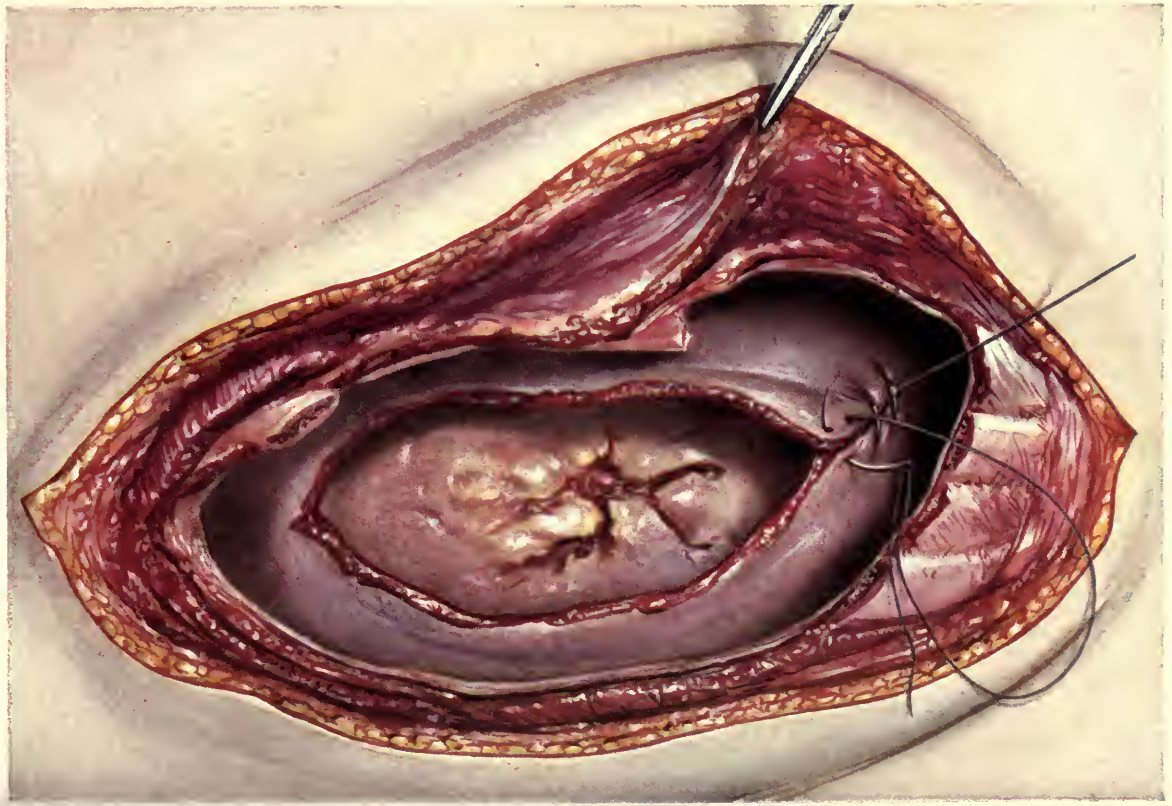
A foreign body, when present, seems to lie generally near the surface of the lung, and can easily be removed; if necessary, a small incision may be made through the lung substance.

Lung tissue may be incised without fear, because any fresh bleeding following incision is easily controlled by suture. The lung should be sutured for two reasons: even if not completely free from organisms, it can deal with a considerable amount of infection, whereas the contamination is very liable to spread backwards along an open track and infect the pleural cavity unless the opening is closed; and secondly, expansion of the lung is facilitated. An open bronchus is rarely seen in operation on a wounded lung, and no special surgical treatment of the bronchi is needed.

Abdomino-thoracic Injuries.—Injuries involving both the chest and abdomen are not infrequent, either as the result of single or multiple injuries. When a missile has traversed both chest and abdomen the diaphragm is necessarily injured,



The chest widely opened.



and abdominal viscera may subsequently protrude into the pleural cavity. This is more commonly found on the left than on the right side because on the latter the liver gives protection.

The diaphragm can only be repaired efficiently from above, therefore it is wise to open the chest first, suture the diaphragm,

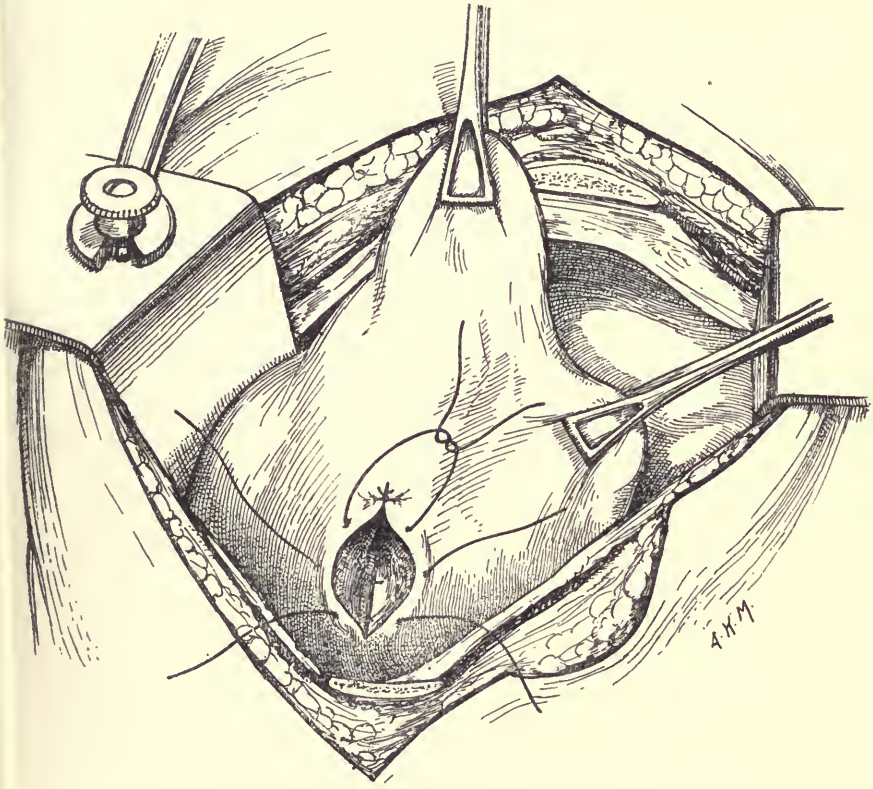


Fig. 19.—Drawing to illustrate method of suture of lung in previous case, Fig. 18, after excision of the wounded area. The patient recovered without suppuration, and was transferred to England in good condition.

deal with the chest as already indicated, and then, if there is evidence of injury to the hollow abdominal viscera, laparotomy may be performed. In the case of a shell fragment having passed through the chest and lodged in the substance of the liver it may be necessary to remove it through the thoracic opening, to excise any devitalized part of the liver, and then suture the diaphragm. Plate XII illustrates the same case as

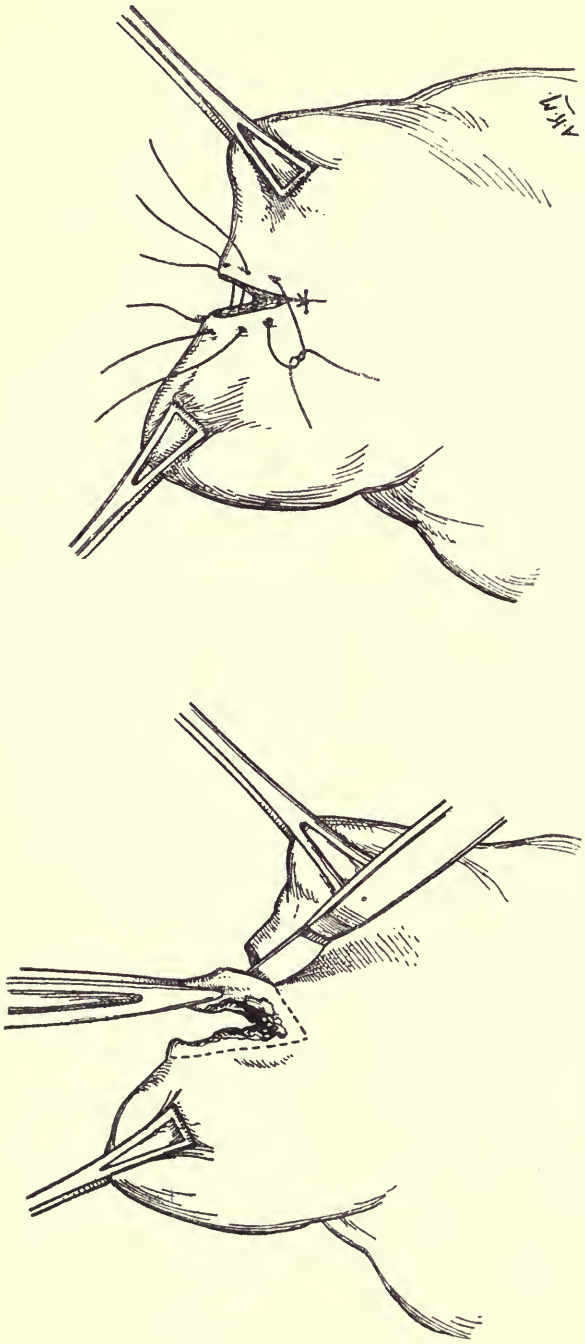


Fig. 20.—Method of excision and suture used for a ragged wound of the edge of the lung.

Fig. 23, and shows the injury when the splintered ribs had been removed after an incision joining entry and exit wounds. The diaphragm had a tear 6 ins. long, and the liver showed radiating fissures with extensive laceration. The diaphragm was sutured and the chest closed. The patient died from shock twenty hours later.

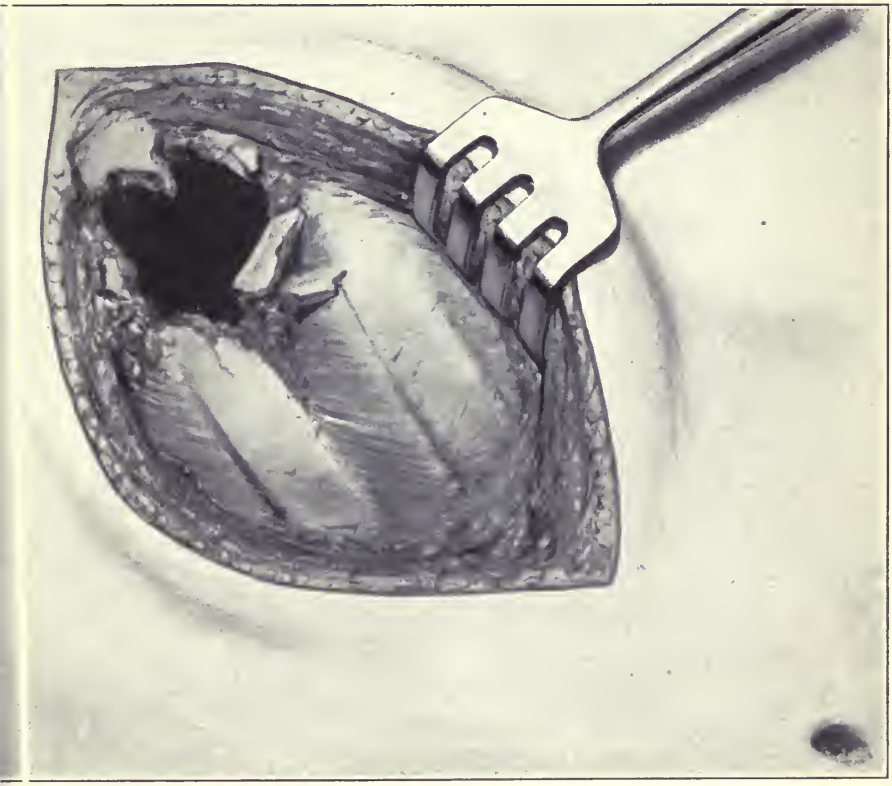


Fig. 21.—A perforating bullet wound with small entry and "explosive" exit. The destruction to ribs and pleura was great, and a large hole leading into the chest is revealed by the first stage of the operation.

The passage of a small missile through the diaphragm may not necessitate repair; in such a case with evidence of injury to hollow viscera the abdomen is afforded preferential treatment.

Cleansing and Closure of the Pleural Cavity.—In most cases it is only necessary to cleanse the pleural cavity by swabbing it dry and clean. If, however, there has been much soiling,

it is advisable to wash it out with either warm saline or eusol. In any case the cavity must be left dry, an essential factor in the early expansion of the lungs. Whether the operation has been performed through the wound or by fresh incision, the chest should always be closed. The relief afforded to the patient is instant and great. An attempt should be made to repair the chest wall in layers—pleura to pleura, muscle to muscle, and skin to skin. Where a large hole has been blown through the chest wall it may be impossible to make the edges of the pleura meet; in that case muscle should be

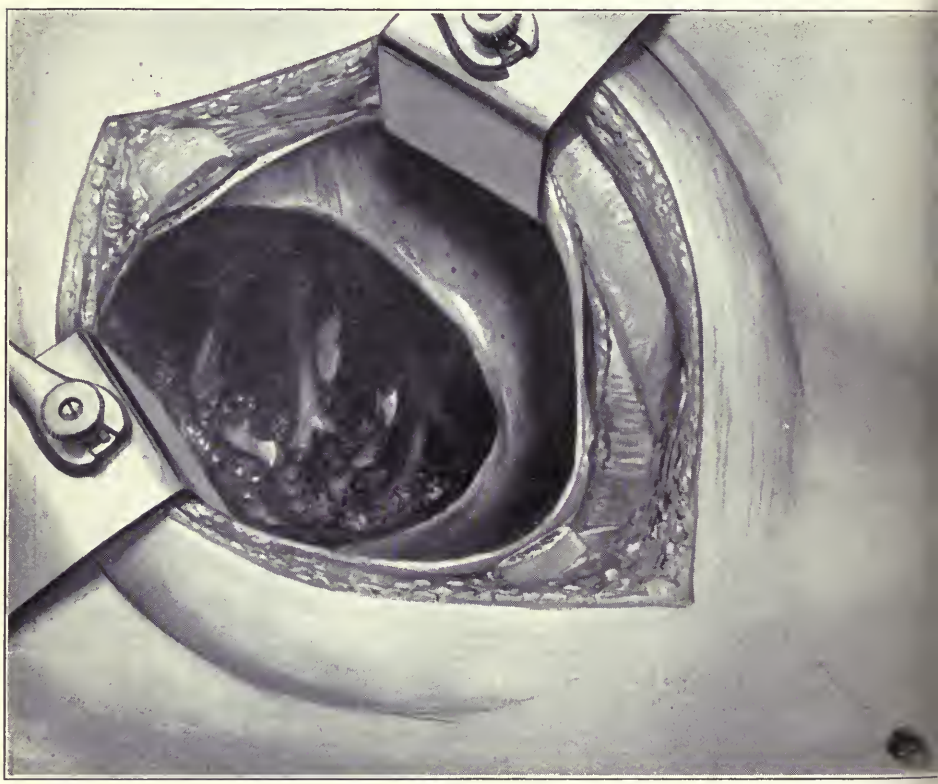


Fig. 22.—Second stage of operation from same case as Fig. 21. The lung, which was adherent to the parietal pleura, shows extensive laceration, and in this lacerated area are rib fragments and visible lung vessels. In this case bleeding was still going on twenty-three hours after the wound, because the lung could not collapse on account of its adhesions. The bleeding points were ligatured and the chest closed. The wound suppurated down to the lung, but the patient made a slow satisfactory recovery.

made to cover the gap, even if a flap has to be cut. Finally the skin should be closed by interrupted sutures. In the majority of cases healing will be by primary union.

Regular post-operative aspiration is generally required to keep the pleural cavity dry, for after an extensive operation there is a fluid exudate which may become infected if not removed. Physical signs are not trustworthy for the detection of such fluid, and the chest should always be aspirated as a routine twenty-four hours after thoracotomy. If only light

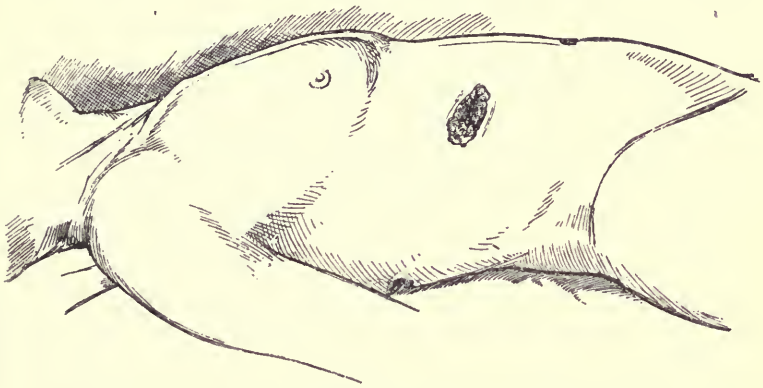


Fig. 23.—Drawing of a perforating shell wound in the right lower costal region. The entry wound behind was slightly smaller than that of the exit in front, but both were large and lacerated. Operation performed twelve hours after the wound.

infection develops, it may be possible to control it by repeated aspirations, since there is no longer any blood clot left in the cavity. But if such infection proceeds to abundant suppuration, the empyema has to be treated by drainage. If the original incision did not lie at the lowest level of the pleural cavity, drainage must be provided by a fresh incision so as to reach the lowermost part of the pleural recess. The longer drainage can be delayed after the primary thoracotomy the better for the lung, because the latter expands more rapidly while the chest is closed and it develops parietal adhesions which make respiration easier when the cavity has ultimately to be drained.

Patients who had thoracotomy performed on them were retained for ten days at least at the casualty clearing station, in order to ensure that they should pass through the danger time of pleural sepsis under continuous vigilance, and also because transport was liable to aggravate such infection.

Crushed Chests.—A certain number of men was admitted to casualty clearing stations suffering not from bullet wounds but from an extensive crushing of the chest, which had been caused by large shell fragments, by falling masses of masonry, or by burial beneath timber and earth when trenches and dug-outs were blown in. The patients suffered from great respiratory distress and were commonly admitted in a seriously collapsed condition. In the worst cases many ribs were fractured and the lungs lacerated by in-driven fragments, while the haemothorax was often bilateral.

The treatment of these patients was difficult, many of them dying from the severity of the injury. If evidence could be obtained by X-ray examination that portions of rib had been driven into the lung, and if the patient could stand operation, then thoracotomy with excision of the broken and indriven ribs, repair of the lung, and suture of the chest might be undertaken. The slighter cases without severe pain and only with hæmothorax were better left undisturbed.

Non-operative Expectant Treatment. — In the less severe types of chest wound where early operation was not thought necessary, the patient was retained under simple medical treatment, the chief duty of the medical officer being to watch for signs of infection.

These patients, who were not operated upon and who with light wounds or a hæmothorax of inconsiderable size did not show distress, might be safely evacuated seventy-two hours after the injury. In times when the number of wounded was great many were evacuated to the base at an even earlier date and did not come to any harm. The journey never caused fresh hæmorrhage. But a number, especially of those with a large hæmothorax, who at the casualty clearing station had exhibited no signs of sepsis, arrived at the base, after a journey of twelve hours or more in an ambulance train, in a state of great distress and with the most serious features of infection spreading throughout the hæmothorax. In all probability these patients were infected at the beginning, and the shaking of the train journey had disseminated the bacteria through the hæmothorax and caused an intense outburst of sepsis.

Patients with bronchitis or congestion of the lungs also stood a train journey very badly. So far as possible, these cases and those with large hæmothorax were retained at the casualty clearing station until the danger of spreading infection had passed away. As a rule they liked to be propped up, and Fowler's position was the easiest. The use of " Fowler's

frames," i.e., a double-inclined frame, placed on the bedstead, obviated the difficulty of the patient slipping down in bed.

There is very often some distress in breathing, especially after transportation by ambulance car. This can be eased by morphia ($\frac{1}{4}$ grain) or heroin hydrochloride ($\frac{1}{20}$ grain). If there is cough and expectoration, a sedative expectorant, such as one containing equal parts of Tr. camph. co., oxymel of squill, and syrup of tolu, may be given; and if there is spasmodic dyspnœa a few minims of Liquor morphinæ acetatis is useful. Sometimes, with difficulty in expectoration, a stimulant mixture with 3–4 grains of carbonate of ammonia and 5 grains of iodide of potassium is better.

Continued dyspnœa caused by a large hæmothorax may be relieved in the first or second day by very slow aspiration, and there is no harm in allowing some air to pass back into the chest through a clean aspirating needle if a too rapid expansion of the lung should chance to cause a fit of dyspnœa and coughing.

Usually within two or three days after receipt of a chest wound which has not carried deep infection with it, the injured man passes into a condition of relative ease. His dyspnœa becomes progressively less urgent; the temperature, which is generally raised for the first two or three days, approaches normal by a smooth curve of decline, and the pulse falls below 90. He sleeps well and his appetite returns. In every respect he is rapidly regaining the appearance of a healthy man, and each day marks an obvious step forward in that direction.

There are now two questions that arise in the care of the case—what should be done with any hæmothorax that is present, and how the surgeon should detect and deal with possible infection of the hæmothorax.

Hæmothorax.—When this is not complicated by a large retained missile or by a severe parietal wound, it does not require thoracotomy for evacuation of the blood. A proportion of these uncomplicated cases do develop empyemata, but the number is relatively so small that it is not practicable to treat all cases of hæmothorax by early prophylactic thoracotomy. Patients with small hæmothorax, reaching up to the angle of the scapula or a little way into the axilla, recover by natural absorption so completely that it is not even necessary to aspirate the chest.

Larger effusions require aspiration on the third to fifth day. This should be done under local anæsthesia, novocaine 1 per cent., taking care that the intercostal pleura is

anæsthetized as well as the skin. It is best to insert the trochar well forward in the axillary region, so as to avoid the blockage of its orifice by fibrinous clot that may be lying in the para-vertebral recess. All the fluid should be removed, and air or oxygen replacement may be used if the patient feels respiratory distress towards the end of the aspiration. As much as four or five pints may be drawn off from a very large hæmothorax, but this is blood mixed with reactive pleural exudate. The fluid blood withdrawn should be centrifugalized and a microscopic film prepared from the deposit so as to obtain early evidence of any sepsis that may be developing in the chest.

Sometimes the aspiration is rendered difficult by clots within the chest, and punctures in more than one place may be needed. If all attempts at aspiration fail so that there is no doubt that the hæmothorax is in the rare condition of massive clot, then the chest should be opened by a clean incision as in the routine described above for thoracotomy, the clot cleared out and the chest closed again.

Pneumothorax.—This is usually associated to a slight extent with hæmothorax. Sometimes there is a complete pneumothorax without hæmothorax, and the lung is then entirely collapsed against the vertebral column. Such cases require watching in respect of the possibility of sepsis occurring; but infection does not often develop with them, and apart from that mischance the pneumothorax should be left alone for its own recovery by simple absorption in the course of the next two or three weeks. Nothing is gained by early aspiration of the air, and such premature expansion of the lung may lead to a fresh leak from the injured bronchus.

Treatment of an Infected Hæmothorax or Empyema.—The ideal principle is clearly that of removing not only the infected fluid, but also all blood-clot, splinters of bone, pieces of clothing and any foreign body, so that the remaining infection shall be confined to living tissues. Also the peculiar structure of the thorax demands that the lung shall be aided to full re-expansion at the earliest possible date, for pleural suppuration is ended only by obliteration of the pleural sac.

Various methods for the treatment of established pleural infection were used during the war. None gave really satisfactory results, but the main fact that did emerge was that the surgeons who took infinite pains in the treatment of their infected cases got the best results whatever the methods adopted. Great care and patience were always rewarded in

empyema cases. The mortality could be reduced from 50 per cent. to 20 per cent. and convalescence shortened. But the treatment of empyemata during the war never reached the desired ideals, and the average results consequently remained unsatisfactory to the very end.

The methods of treatment that may be applied in the early stage of infection before the free formation of pus are :—simple aspiration ; thoracotomy, cleansing the pleural cavity and immediate closure ; thoracotomy, with Carrel-Dakin cleansing and secondary closure of the chest ; simple open drainage.

Aspiration alone may sometimes succeed in controlling an infection when it is clinically mild. If this method is used, it must be done repeatedly. It is rarely satisfactory, because infected blood clot cannot be removed, and this material resists sterilization by the body fluids for a long time. Most of the cases in which this method was tried had ultimately to be treated by drainage. It is also most dangerous to aspirate an infected hæmothorax and then send the patient on a train journey, since travelling may excite a rapid increase of sepsis, and result in an overwhelming intoxication. The method is usually only applicable to cases that can be kept for a long time under close observation in the same medical unit.

In quite early cases it is reasonable to open the chest widely, to clear out all the blood-clot together with accessible bony splinters and foreign bodies, and then to close the chest. This gives the collapsed lung the best chance to expand and obliterate the cavity. Aspiration repeated during the next few days will suck off any effused fluid, and if the aspirated fluid becomes purulent, and the chest has to be drained, it is easy to push a tube through the wound already made, provided that the latter is in a low enough position. A few cases treated in this way proved successful ; the chest remained closed and convalescence was quick, but this treatment, to be successful, generally needs to be carried out within two or three days of receipt of the wound, and it must be carried out thoroughly. As a rule it was a failure in the presence of streptococcal infections.

Thoracotomy followed by Carrel-Dakin cleansing and secondary closure, which had been introduced by Tuffier in the French and by Depage in the Belgian services, began to be adopted towards the end of the war in the British service ; the results from it were most encouraging though the method was laborious. For this treatment the chest is widely opened, and the pleural cavity cleaned of all

blood-clot and foreign substances. The opening into the chest is then partially closed, and several Carrel-Dakin tubes stiffened by wire are pushed through the narrow opening in such a way that the tubes reach to the uppermost recesses of the empyema cavity, while the outlet is almost blocked by them. Dakin's solution is then injected regularly through the tubes, which are temporarily removed every twenty-four hours, and the pleura completely washed out. In this way the cavity is progressively disinfected, while the lung begins simultaneously to expand. After a week or longer, when microscopic films from the pleural cavity show that the infection is largely subdued, the chest is closed by secondary operation. The residual pneumothorax then undergoes absorption, the process being aided by aspiration of any fluid that has collected.

Simple open drainage by resection of a piece of rib, rather than through an intercostal space, was at all times used more than any other method during the war. At first, only a small opening was made and a rubber tube inserted. Later the method was improved by a larger opening, through which the blood-clot and, perhaps, the foreign body could be removed from the interior of the chest. Many of those who survived the danger period of acute infection did well; others recovered very slowly through a prolonged convalescence complicated by wasting, suppuration and a lung that never regained its normal volume. Various devices were used in the hope of aiding expansion of the lung by suction through the drainage tube, while the hole around it was temporarily closed by sutures. They were occasionally of value, and Sprengel's pump certainly did aid in keeping a pleural cavity free from accumulated pus when the surgeon had made his opening too high for adequate drainage. The retention of pus below the drainage outlet was also caused sometimes by the sinking down of an originally high diaphragm to its normal level. In either case the condition often required a fresh drainage opening at a lower level.

In the later stage of a hæmothorax with abundant pus, thoracotomy and complete cleansing are less advisable; at any rate, immediate closure after thoracotomy is impossible. The chest must be opened and drained. A wide opening should be made, and the contents removed with very light handling. Subsequently the drainage hole may be partly closed and the cavity cleansed by some form of irrigation in the hope that it may be possible later to attempt surgical closure. Continued fever and wasting after the first

resection are generally caused either by imperfect drainage and pus retention, which can be corrected, or by purulent bronchitis. Patients operated on for empyema rarely die when once they have survived the first two or three weeks of acute infection.

Treatment at Base Hospitals.

Whether the casualties reached the base on the third day or in the third week after being wounded the attention required was of the same nature, for it is all summed up in the need for vigilance to detect the development of intrathoracic sepsis. This applied even more to patients who had undergone prophylactic thoracotomy with cleansing, for the operation might have failed in its aim, and the physical signs of an empyema are more difficult of interpretation in the presence of a pneumothorax created by the early thoracotomy.

Men who arrived in undue distress from the journey should have their chests explored by a needle if their condition did not improve in a few hours. The exploring needle was also used in all doubtful cases with fever which did not appear to be recovering satisfactorily.

Extensive intrathoracic operations were undesirable at this stage, and foreign bodies, in the absence of sepsis, were left alone. A simple hæmothorax might be aspirated at any date, and the sooner this was done the better for recovery.

Evacuation overseas was not allowed until the danger of a late development of sepsis had passed away. It was advisable to retain in France all cases in which there had been a pleural or pulmonary lesion for two weeks from the date of the wound, and the time was extended to three weeks whenever practicable. Not a single instance was notified during the war of fresh hæmorrhage having been caused by evacuation across the Channel.

Empyema cases that had been drained might be transferred as soon as their temperature was normal and the patient was obviously regaining health.

Treatment in the United Kingdom.

The period of treatment in the United Kingdom comprised the period of recovery commencing about the third or fourth week after a chest wound. The immediate danger from acutely developing sepsis would by this time have passed away.

If fluid in any considerable quantity, 20 ozs. or upwards, were still present after this interval it should be removed at once by aspiration. From the end of the fourth week onwards the patient should get up from bed and be encouraged to take exercise, increasing daily but always less than that producing fatigue or pain. Absorption of any fluid and of blood-clot, and early re-expansion of the collapsed lung are greatly favoured by walking and by moderate chest exercises. Deep breathing should be encouraged in various ways, but blowing up air pillows and so on is the least useful method since the chief effect of this expiration against resistance is to produce over-distension of the healthy lung. A superficially suppurating parietal wound does not contraindicate such physical exercises.

When treated in this way patients recovered rapidly; there was usually no loss of movement or flattening of the chest, and the respiration in time became good enough for the severest effort. Thus a patient with shell fragment retained, from whom 60 ozs. had been removed by aspiration, was back on duty again in France two and a half months after his wound; and in similar cases of large hæmothorax it may be quite impossible after six months to detect any abnormal symptoms or signs.

Cases of large hæmothorax that had not been aspirated, and cases of moderate size that had not received sufficient physical exercises showed poorer recovery. Meakins and Walker made a careful study of the progressive physical deformity that resulted in these cases. There was drooping of the shoulder, deformity of the muscles of the shoulder girdle, and in the worst cases a conspicuous shrinkage of the thoracic wall together with curvature of the spine. These changes occurred only in cases of fairly large hæmothorax that had not been aspirated, or after empyemata that were not drained until several weeks had elapsed. They were never associated with simple wounds of the muscles and bones of the chest wall, nor even with injuries of the lung except when a collection of fluid had been left for many weeks in the pleural cavity. Even in these cases the deformity could be partly checked by special exercises to develop the muscles of the injured side, the healthy side of the chest being in the meantime immobilized by some special posture.

Pneumothorax required no special treatment, for generally it was absorbed before the third or fourth week, but a few cases were reported in which the pneumothorax recurred

acutely with a fresh air leakage as the result of physical effort in the second month; none of these had any serious results.

Empyema cases had generally been treated by drainage before they reached England. As soon as the fever was controlled and the patient was regaining health, it became advisable to get him out of bed and start physical exercises. This might at first increase the discharge of pus, but the lung soon commenced to expand and in a few weeks the sinus closed. Systematic lavage of the empyema cavity with eusol aided the dislodgment of suppurating blood-clot and accelerated healing.

Most empyema cases heal within six months, though sometimes after a preliminary healing the sinus may break open again. In the minority chronic sinuses persist and chest deformity develops. A suppurating cavity that does not appear to be healing within three months requires surgical treatment. Carious rib fragments should be removed, the empyema cavity explored, loculated recesses opened up by cutting through adhesions, and the lung surface freed by some method of decortication. Estländer's operation of cutting away the ribs, so that the empyema cavity may be obliterated by the falling in of the thoracic wall, has a maiming effect upon the patient. It should only be used in cases where persistent and uncontrollable suppuration threatens life, and as a matter of fact it was most rarely employed in England for gunshot wounds of the chest. On the whole, the treatment of cases of chronic suppurating sinuses from empyema was not considered as attentively in England as this group of injuries deserved. In 1920 there were still pensioners suffering from persistent sinuses, while the operation of decortication had been tried in a few instances and found to be successful.

Rifle bullets and small pieces of shell retained in the lung or pleural cavity in non-infected cases rarely caused any disability, and their presence did not delay the return of a soldier to full duty. Therefore they should be left alone, unless they give rise to a continuance of such symptoms as pain, cough, dyspnœa, expectoration, or even hæmoptysis. If these symptoms persist for two or three months, the foreign body should be removed, provided that X-ray localization proves it to be in some accessible position. Missiles lodged in the hilum of the lung are perhaps dangerous to the patient, but they are difficult of access.

Two types of operation have been used, the method of Petit de la Villeon, and the open method. The former operation consists in the introduction of a special pair of forceps through a very small incision made between two ribs. After its position has been accurately determined by the X-rays, the foreign body is gripped and removed by the forceps under the guidance of the fluoroscopic screen. There are many objections to this method, and most surgeons now agree that the safer way is that of open operation.

Open thoracotomy for the late removal of a foreign body should not be attempted until all infection in the parietal wound has vanished. Such thoracotomy in a healthy man who has completely recovered from the shock and sepsis of his original wound, is a relatively simple procedure. It should be planned in such a way as to give minimal weakening of the thoracic cage

Foreign bodies retained in cases complicated by empyema did undoubtedly delay convalescence, and the long suppuration often resulted in deformities of the chest and inability for full service. In septic cases consideration should always be given to the possibility of removing the missile, which often moves during the processes of suppuration into a position in which it may become accessible without any deep operation.

Diaphragmatic hernia occasionally occurred on the left side in men who had been shot through the diaphragm and had not undergone early operation for repair of the rent. Such bulging of the stomach and splenic flexure of the colon into the pleural cavity developed progressively as the gap in the diaphragm widened under the strain of muscular effort, and it was therefore seen only in men who had been discharged from hospital and returned to duty.

As the hernia formed there was usually a lengthy period during which the man complained of indigestion, occasional vomiting after meals, flatulence, and sometimes intrathoracic gurglings. The existence of such symptoms in the case of an old wound of the left hypochondrium ought to lead to the suspicion of a diaphragmatic hernia and to an immediate X-ray examination of the colon as well as of the stomach. Ultimately acute obstruction might suddenly appear, and the diagnosis of the cause of the obstruction, if the history of the old chest wound were neglected, was often difficult because the abdomen might be flat while the left base of the chest presented misleading physical signs, such as absence of breath sounds, dullness or resonance on percussion with metallic tinklings, and a heart displaced to the right.

The condition requires prompt surgery. Experience has not yet shown whether it is better to operate through the thorax or the abdomen, but the latter route leads to difficulties in dealing with the high vault of the diaphragm. Probably it is better to enter both cavities simultaneously by resecting the ninth rib and carrying the incision forwards to the umbilicus.

Mortality and Invalidism.

The mortality statistics already given deal with the results of chest wounds in general. The death-rates in different types of chest injury, so far as they are known, together with the periods of invalidism among the survivors, both for those who were treated by early surgical operation and for those who were left to their own natural powers of recovery, require special consideration.

Information on this point, however, is far from complete, and it is still somewhat early to discuss the ultimate history of chest wounds. The most detailed analysis is that made by W. L. Mann on 600 cases treated by him at a casualty clearing station behind Ypres from 1916 to 1918. At first the wounds were treated expectantly without operation; later, the practice of early thoracic operation was adopted for all wounds that were judged to require it. The after histories of nearly all these cases were subsequently determined by investigation of the case sheets from home hospitals and of other records, and so the mortality in invalidism in the two series was contrasted.

Fortescue-Brickdale analysed the times of invalidism in a consecutive series of 600 cases of chest wound, who had been transferred from France and were under his care in a special hospital in England. Many of these had undergone early thoracotomy in France. In addition to this there are some analyses of invalidism before early surgery came into vogue —of 170 selected cases of different types by Elliott, and of 70 consecutive cases by Meakins and Walker.

Parietal wounds were in themselves an occasional source of disability, especially when there was a painful scar in such a position as over the scapular region where it was liable to be pressed upon by equipment. The ordinary parietal wound or a perforating lung wound without obvious hæmothorax did not require detention of the patient under medical care for more than two months.

After the first two days there were no deaths among patients with a sterile hæmothorax. The average stay under medical treatment was three months; and about 5 per cent. were

invalided from the army, though these were almost all for other injuries associated with the hæmothorax. Adhesions, especially those around the pericardium or at the diaphragm, occasionally produced some disability from pain and dyspnœa on physical effort. The majority of the men were fit for full duty in less than six months. Cases with small effusions of about 30 ozs. at the first week and extending up to the scapula and half-way to the axilla, recovered with equal rapidity whether they had been aspirated or left alone. The chest was normal in 80 per cent. of such cases within two months of the wound. Larger effusions gave bad results if not aspirated, but if aspirated early there was rarely any chest deformity, and the recovery was only a month later than in cases with the smaller effusions.

Those with massive clot gave worse results but fortunately were rare. They often developed a late and subacute empyema, recovery from which after drainage was attended by considerable deformity of the chest. It was clearly an advantage for these cases, if they could be detected, to be treated by thoracotomy and evacuation of the clot as early as possible.

In respect of early prophylactic thoracotomy on a case of hæmothorax apart from the question of massive clot, Fortescue-Brickdale gives the following figures for sterile hæmothorax. In 21 cases emptied by thoracotomy on the first or second day, the average length of stay under hospital treatment was 130 days. In 73 cases treated by aspiration alone, the average hospital stay was 88 days.

From this it is evident that thoracotomy is not a desirable form of treatment for simple hæmothorax since it prolongs invalidism. Moreover, it must be borne in mind that an extensive thoracic scar together with rib removal is regarded as an additional disability to a man in respect of pensions, and that it generally results in an addition of 10 or 20 per cent. to his pension allowance. But the argument against thoracotomy for sterile hæmothorax should not neglect the fact that many of the cases so treated would have developed empyema, with a longer period of invalidism, if left alone ; and that they were chosen for operation because they had wounds of a type which was known to be liable to sepsis.

The mortality in cases of septic hæmothorax and empyema was nearly 50 per cent., and these cases of sepsis in France formed 20 or 25 per cent. of the total of all chest wounds. Very few deaths occurred after the first two weeks. At least

one-third of the empyema cases were ultimately discharged as unfit for service, simply on account of the chest condition. The best end results were seen when drainage had been performed early in the first fortnight rather than later. The average total stay in hospital for 31 cases under Fortescue-Brickdale was nearly seven months. A fair proportion of empyema cases were back on full duty in France within a year of their wounds, but in general the men with old empyemata were left with collapsed lungs and were never fully efficient again.

Injuries associated with open pneumothorax (sucking wound), when left with only a tight pad over them, sometimes closed satisfactorily in twenty-four or forty-eight hours. The majority, however, developed empyemata and ran a dangerous course. Early thoracotomy had a favourable influence on this group of wounds. Mann reports 51 cases with early operation, of whom 45 per cent. died (or 10 per cent. if complicating wounds were excluded), and 27·5 per cent. of the total, not of the survivors, were returned to duty. On the other hand, 112 cases treated expectantly with only a pad on the wound gave a mortality of 53 per cent. (or 20·5 per cent. for uncomplicated chest wounds).

The early mortality in abdomino-thoracic wounds was always high, in fact higher than for a wound of the abdomen alone. Mann's records give a list of 94 cases, of which 34 were treated by early operation. The mortality was 50 per cent. even after operation, but half the survivors returned to duty. The mortality in non-operated cases was 60 per cent., and there was a less satisfactory number returned to duty. Soltau's figures in an army area in the autumn of 1917 showed 55 cases of abdomino-thoracic operations at the casualty clearing stations with 58 per cent. of deaths, while the base records for the same time prove that the survivors from these extensive operations recovered well and rarely had empyemata. Gask and Wilkinson record 12 operated cases with a mortality of only 16 per cent. Lockwood and Nixon give a consecutive series of 29 abdomino-thoracic operations with a mortality of 38 per cent.

These figures for operations include cases of the greatest gravity, and they rather hide the fact that many complete recoveries were obtained by operations on patients who otherwise would have undoubtedly passed through a period of most dangerous infection. Details of such cases are given in the original papers to which reference is made.

In Elliott's series the retention of a foreign body did not affect the time of return to duty or the efficiency of the men, provided that the pleural cavity had remained uninfected. Rudolf, in a series of 50 cases of retained foreign body in England, noted that such men had no more trouble with cough, dyspnœa or pain than was complained of by men in whom the missile had passed clean through the chest.

Wounds where a foreign body lay in the pericardium or heart were always regarded with fear of subsequent trouble, and these cases as a rule were discharged as soon as possible from the army. There is no evidence, however, that these few cardiac wounds have led to serious after results.

Other cases with retained foreign body have generally received a slight increase for that reason in their pension allowance, but as yet there have been very few cases in which hæmoptysis or any untoward symptoms have actually been observed in such men after discharge from the army. On the other hand, a retained foreign body certainly increased the incidence of unfitness in men where an empyema had developed in connection with it.

Neurasthenic apprehensions of disability have not been an obvious feature in the later results of chest wounds; nor has tuberculosis been noticed as a sequel.

In general the pensionable disability for chest wounds has not so far proved to be high. In the year 1919–1920 there were 23,222 examinations made by medical boards upon pensioners claiming chest wounds as invaliding disability; this number formed 1·5 per cent. of the total number of examinations during that period. The disablement found in examination for pensions is on the average slight. Out of 1,431 pensioners for chest wounds classified in ordinary routine work in the month of October 1920, there were only 22 with the full 100 per cent.; 129 or 9 per cent. received 40 per cent. disability; 323 or 22·5 per cent. a 30 per cent. disability; 397 or 27·7 per cent. a 20 per cent. disability; while 322 or 22·5 per cent. had less than 20 per cent. disability. Three-fourths of the men, therefore, received pensions not exceeding 30 per cent.

The killing effect of chest wounds in the war, where so many of the injuries were caused by shell fragments or bullets at short range, was exceedingly high. Perhaps as many as 70 per cent. of the men struck in the chest died on the field, and 27 per cent. of the survivors died within the next two weeks. But those who lived were not seriously disabled. Even those who survived from empyemata, though often unfit for full military

duties, were still capable of good and useful work in civilian life. Any means that could save the lives of men with chest wounds were well rewarded by the excellence of the ultimate recovery.

General Conclusions.

The following principles are those that from the experiences of the war of 1914–1918 seem to be fundamental in guiding the arrangements which should be made whenever possible for the treatment of chest wounds.

(1) Where the climatic conditions are wet and cold, all chest wounds must be saved from unnecessary exposure since they are otherwise very prone to develop serious complications of bronchitis and broncho-pneumonia. These precautions do not exclude open air treatment, provided that the men are kept warm.

(2) Wounds by shell fragments and rifle bullets frequently cause severe laceration of the ribs and of the lungs. Survivors from the field are liable to death either from hæmorrhage and shock in the first two days, or at any time up to the third week from infection developing within the pleural cavity. Prompt surgical treatment can diminish considerably the numbers of such deaths, and also lessen the period of invalidism by preventing the development of empyemata. Facilities must, therefore, be provided for the surgical treatment of a varying proportion of the chest wounds within a few hours of their occurrence and at a distance from the front which involves the shortest possible journey. These conditions demand good surgical and nursing equipment, X-ray apparatus, the advice of a physician, and means for bacteriological examination.

(3) The surgeon must be well trained in his technique, or the results will be but little better than those of simple expectant treatment. The cases for operation must be wisely selected, for the majority of chest wounds do not require any operative treatment. Each case must be judged on the nature of the wound found, rather than by considering the missile that produced it. But generally speaking, where wounds are caused chiefly by long-range rifle bullets, extensive provision for early surgical operations is not likely to be required.

(4) Casualties with chest wounds are made worse by travelling. All journeys in the first three weeks should be as short as possible and should not occupy more than twenty-four hours, because in that period of time the features of dangerous

sepsis may suddenly develop and the patient's life be lost if he cannot at once receive surgical aid.

(5) During the first three weeks all patients must be carefully watched for the possible development of intra-pleural sepsis. After that period they need steady attention in order to ensure good expansion of lungs that may have been collapsed beneath a hæmothorax or an empyema. Physical exercises must be used. In particular, cases with a discharging empyema require at all times very close individual care in order that a good recovery may be obtained.

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CHAPTER XVI.

INJURIES TO THE PERICARDIUM AND HEART.

THE War Office collection of pathological specimens contains a series of injuries to the heart which illustrates every form of lesion that has been described from the accumulation of experience during the whole history of surgery. Yet when an attempt is made to gain some idea of the frequency with which these injuries are received in comparison with that of other visceral lesions, no reliable data are available. It is remarkable that interest in the surgery of the chest has been almost entirely centred in the subject of injuries to the lungs and the pleuræ.

Occasional references may be found to this subject. Thus in a paper by Captain H. Henry and Major T. R. Elliott on the morbid anatomy of wounds of the thorax, one hundred fatal cases are considered, amongst which there is a remarkable case of a wound of the heart in which the cardiac lesion was not the immediate cause of death. Again Captains R. G. Dixon and P. McEwan encountered one case of wound of the heart amongst 123 gunshot wounds of the chest which came under treatment in a casualty clearing station. Captains J. E. H. Roberts and J. C. Craig met with one laceration of the pericardium in 33 fatalities which occurred amongst 199 chest wounds; and Captains Lockwood and Nixon met with one wound of the heart amongst 40 fatal abdomino-thoracic injuries.

While, therefore, no records are available upon which to form a reliable opinion as to the proportionate frequency with which death follows as a consequence of uncomplicated wounds of the heart, the natural inference is to the effect that the traditional view is correct, and that the immense majority of men who receive these injuries find their end upon the field of battle.

Injuries to the Pericardium.

Perforation of the sac of the pericardium with or without injury to the heart is not uncommon. The simplest form is that in which the cavity is traversed by a bullet, and in the absence of visceral complications such wounds may be of little importance.

The outstanding feature of gunshot injuries in the war was the frequency with which the missile was a fragment of a shell, bomb or grenade, and hence the common sequence of infection and its consequent dangers. Infection of the pericardium in some instances resulted from wounds which did not actually penetrate the cavity; this in the majority of cases happened in connection with compound fractures of the sternum in which mediastinal cellulitis developed.

Case 1 (W.O.C.*) illustrates a minimal injury to the pericardium. On the outer wall of the sac some ecchymosis of the mediastinal tissue is visible. Within, a small lacerated puncture ⅛th of an inch in diameter in the anterior wall is surrounded by a more or less circular patch of ecchymosis some 4 ins. across. A small quantity of altered blood was present in the cavity when opened, and a shaggy adhesion on the front aspect of the heart. The anterior surface of the right ventricle is bruised, and on the posterior aspect signs of bruising are also present. The minute fragment of bomb which occasioned the injury was retained in the posterior part of the pericardial cavity.

Case 2. Figs. 1 and 2 (W.O.C.) illustrate an extreme instance of the escape of the heart from gross injury, even when the pericardium had suffered an extensive laceration in its central part. Such a lesion could only be produced by a fragment of shell travelling at a comparatively low degree of velocity; yet this specimen shows that very considerable force was exerted upon the sternum.

The patient, a gunner, aged 25, was admitted into No. 7 Canadian General Hospital under Major Platt. The man was very ill. Two wounds were present; one of the left arm, the second, an opening into the left side of the thorax an inch outside the heart. Respirations were rapid, the pulse weak and irregular. There was pus in the left pleura, and the cardiac dullness was increased in extent: Sixteen days later an attack of hæmorrhage occurred, and the man died the same day. The condition throughout had been so serious as to negative the question of submitting the patient to the strain incumbent on an X-ray examination.

At the autopsy the wound in the arm was found to have perforated the biceps without causing injury to the humerus. The aperture of entry in the chest wall was situated above the left nipple, and thence the missile had passed between the ribs and caused a comminuted fracture of the sternum at the level of the junction of the third costal cartilages. Fig. 1 shows the missile in position, and one large fragment of the comminuted fracture completely stripped of its coverings. The fracture extends over the entire width of the sternum. The fragment of the shell lay in relation to the right auricle of the heart, and a trifling injury to the wall of the right ventricle was evident while the specimen was in the fresh state. Fig. 2 shows the extent of the laceration of the pericardium. About three ounces of blood were present in the cavity of the sac at the time of the post-mortem examination. The lungs were engorged with blood, and the abdominal viscera soft and pale.

Several specimens in the War Office collection show perforations of the pericardium in connection with wounds of the heart.

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* W.O.C. means War Office Collection in the Museum of the Royal College of Surgeons.

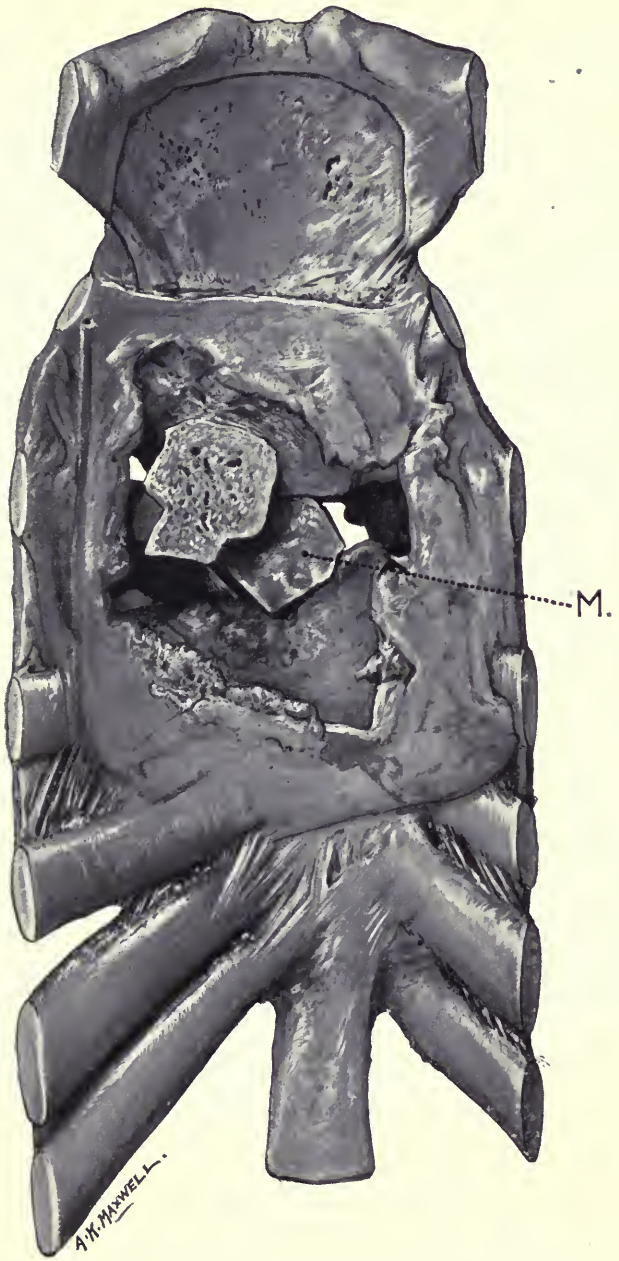

Fig. 1.—Comminuted fracture of sternum caused by a missile striking its posterior aspect.

Fig. 2.—Laceration of pericardium.

Case 3 (W.O.C.) is an interesting example. In this specimen a fragment of shell roughly cubical in shape and about half an inch in diameter lies impacted in the aperture in the pericardium and projecting into the cavity. An abrasion is seen on the surface of the right ventricle, while the presence of shaggy exudate on the surface of the parietal and visceral layers shows death to have resulted from infection and consequent pericarditis.

The lacerations do not present any special features, the chief variation depending upon the extent of ecchymosis and the amount of blood infiltrating the mediastinal tissue. The latter is often abundant and not rarely has become infected.

Case 4 (W.O.C.) exhibits a perforation of the pericardium complicated by a superficial linear wound on the surface of the right ventricle. A severe degree of mediastinal hæmorrhage is present. The pericardium is acutely inflamed throughout, and deposit of lymph on both the parietal layer and epicardium abundant. The patient died upon the third day after reception of the injury.

Case 5 (W.O.C.) is a specimen similar to Case 3. A large dent corresponds with the outline of the missile, a cubical fragment of shell $\frac{3}{4} \times 3\frac{1}{4}$ ins. in size. The patient, who was the subject of multiple wounds, died on the 19th day, signs of pericarditis developing on the 14th. At the autopsy, thick yellow pus lay in the pericardial sac, and the membrane throughout was covered by a thick coating of inflammatory lymph. The entrance wound was low in the right chest posteriorly, a hæmothorax developed and at the time of death was infected; a subphrenic abscess was found in connection with a wound of the right lobe of the liver.

The most common sign of an injury to the pericardium is the development of a friction sound, due either to the presence of blood or to inflammatory changes. There is little evidence that bleeding and the development of hæmopericardium occur in the minor wounds uncomplicated by injury to the heart. In the recorded post-mortem examinations the common description is "a small quantity of blood, or of bloody fluid." Some further remarks on the clinical signs will be found on p. 437, where retained foreign bodies are dealt with.

In the case of shell wounds infection is common, and typical suppurative pericarditis associated with abundant development of lymph forming a shaggy covering to the heart is met with. The primary infection may be very gross; thus in a case quoted by Dixon and McEwan "a piece of khaki cloth with a small quantity of fluid and clotted blood" was found at the autopsy.

In this connection a case published by Major Littler Jones may be briefly quoted, although it is complicated by a shallow non-penetrating furrow wound of the ventricle.

Case 6. A pipe major, aged 38, was admitted to the Liverpool Merchants' Hospital on the second day after receiving wounds from fragments of a high explosive shell. One wound was situated in the fourth left intercostal space, three inches within the nipple line, and a second in the seventh interspace vertically below the left nipple.

Both wounds were infected, and the patient was expectorating blood. The breath sounds were faint at the left base, and the heart sounds were very weak. Dullness extended from one base to the other, and the presence of blood in both pleural cavities was suspected.

The man was short of breath, and up to the 6th day he got practically no sleep. "Stretching pain" was complained of at the left base. The heart sounds became inaudible, but no material alteration occurred in the volume or rate of the pulse.

On the 8th day the patient was exhausted from want of sleep, the complexion was dusky, and the conjunctivæ had acquired an icteric tinge, but the pulse was 70, the temperature was normal and the chest wall was free from œdema.

In spite of the fact that the general condition had precluded an examination of the bases of the lung by auscultation, in view of the patient's desperate state it was considered wise to make an examination with the fluorescent screen. It was then at once discovered that there was practically no blood in the pleuræ, and that the extensive dullness corresponded with a pericardial effusion. It was assumed that this was due either to renewed hæmorrhage or to the occurrence of infection.

The pericardium was exposed by resection of half the width of the sternum and portions of the 7th, 6th and 5th costal cartilages. When the sac was opened by a vertical incision, the heart at once came forward and plugged the aperture; when the organ was pushed back, a quantity of gas, froth, and twenty-two ounces of foul smelling blood-stained fluid escaped. The fingers were introduced and adhesions between the parietal and visceral layers of the pericardium separated. A deep groove in the upper border and anterior surface of the ventricle was seen, and also an opening by which the missile had left the pericardium and entered the left pleura and lung. There was no recent hæmorrhage. The patient's colour, which had up to the moment of opening the pericardium been dull and dusky, at once assumed a healthy aspect, and his pulse became stronger. Fluid and blood due to the separation of the adhesions were mopped out, and a flanged rubber drainage tube was introduced through eusol dressings into the sac. The heart throughout was tolerant of manipulation and remained so during the dressings. Part of the wound in the chest wall was closed by suture, and the patient much relieved by the operation was put back to bed.

From the fluid evacuated *B. perfringens* and enterococci were cultivated. An X-ray plate developed after the operation showed a much distended pericardial cavity almost circular in shape; and towards the centre of the opacity a more transparent area indicated the presence and the position of the gas, which had not been suspected before operation.

Eusol was first used for lavage, then hypertonic and later normal saline solution; all caused pain. Iodine water, 1 or 2 drachms to the pint, was substituted and suited well. Pushing the heart on one side caused neither pain nor distress, a catheter was sometimes introduced into the deep part of the sac behind, and once a large piece of coagulated lymph resembling a cast of the posterior part of the sac was extruded. No serious trouble was experienced with regard to drainage, and in seven weeks the wound had healed completely. The base of the left lung gave cause for some anxiety, but nothing materialized. At one time the daily excretion of urine fell to twelve ounces with some œdema of the loins. At this time the pulse became barely perceptible, but not alarmingly frequent.

Thirteen weeks after the injury the following report on the condition of the heart was made by Captain MacIlwaine:—"There is no evidence of either hypertrophy or dilatation, no murmurs are to be heard, neither are the cardinal signs of adherent pericardium present. Systolic blood-pressure 108 mm. Hg., diastolic 85 mm. by auscultatory method. An electrocardiogram shows a regular rhythm, with no abnormal mechanism of beat, except a slight inversion of the T wave in lead II. It is difficult to map out the left margin of the heart at the apex, as the cardiac dullness is continuous with a dull area in the axillary region.

An X-ray plate taken by Captain Crymble shows no increase in the size of the heart.

At this period the patient was enjoying short walks, his urine was normal, there was no œdema at the ankles, and in short, as far as it was possible to say, he had regained his previous condition."

Major Littler Jones' case is one of extreme interest from many points of view. It affords an excellent example of the insidious progress of an anaërobic infection, its development without serious rise of temperature or pulse, the intense toxæmia liable to be associated with it, and the fact that when such infections develop in a closed serous cavity great over distension may result without accompanying œdema of the soft parts covering it. The instantaneous relief afforded by operative measures is also striking and characteristic.

The positive information afforded by an X-ray examination is a noteworthy feature, but in spite of its utility the clinical observation of complete disappearance of the heart sounds together with the increase of præcordial dullness would in themselves furnish sufficient evidence to act upon.

Retained Foreign Bodies in the Pericardium.—A large number of instances in which a fragment of shell lodged in the cavity of the pericardium or in its immediate neighbourhood has been recorded. It is naturally impossible in the majority of these to exclude the existence of minor injury to the heart. In such cases an X-ray examination affords the only certain means of arriving at a correct diagnosis, although here confusion may be caused by the difficulty of localizing the foreign body with certainty. The main indications that it is outside the heart wall or its cavities are the nature and periodicity of movement which tends to correspond with that of respiration rather than that of the cardiac cycle. Even here a further difficulty is met with since cardiac movement may be imparted to a foreign body lodged in the lung and completely outside the pericardium.

It may be mentioned here that the signs of injury to the pericardium are by no means always conclusive, and on this point some quotations are instructive.

Captain Nixon in a paper on chest wounds makes the following statement with regard to friction sounds in the cardiac area. " A heart beating in surgical emphysema of the substernal tissues may give rise to a friction sound indistinguishable from pericarditis, or to a remarkable churning sound mistakable for hæmo-pneumo-pericardium. An adjacent pneumothorax will give to the normal heart sounds an exaggerated resonance or reverberation, and if friction is

present, either from pericarditis or from surgical emphysema, or from hæmo-pneumo-pericardium, the noises that may result are astonishing, although with experience they become unmistakable." Speaking generally, if the missile has struck the heart with or without penetration, rapid or irregular action results especially if the posterior aspect or the neighbourhood of the intraventricular septum is the site of the blow.

According to Captains W. A. Rees and G. S. Hughes, in several cases in which the track of the missile was in close proximity to the heart a transient pericardial friction sound developed. In nine cases in which the missile had either lodged near the heart or had passed in its immediate proximity, loud "tapping" sounds were heard over the cardiac area. In each case these sounds were quite distinctive and similar, varying only in intensity. They were most marked at the first examination and persisted for a variable time, occasionally only twenty-four hours, but in one instance they were still present when the patient was evacuated fourteen days later. The sound continued even when the breath was held, although the intensity varied with respiration, increasing with inspiration and diminishing with expiration. It was synchronous with the heart beats and when loud rendered the normal heart sounds inaudible. In four patients the sound could be heard with the ear held some four inches away from the chest and even the men themselves were conscious of it. The sound had no resemblance to pericardial friction, and in the cases referred to there was no suspicion of gas being present in the pericardium. In one case examined under the X-rays a missile could be seen, at the end of the upward movement due to inspiration, to oscillate from side to side synchronously with the cardiac contraction. This oscillation corresponded in time with the moment of maximum intensity of the sound, although in this case an interval of normal lung transparency an inch and a half in width intervened between the shadow of the heart and that of the foreign body. The authors point out the difficulty in accounting for this "tapping" sound since it is associated with so many differing conditions. When a foreign body is present it may be imbedded in the substance of the heart; on the other hand, there may be no foreign body in the chest at all. The suggestion is advanced that a small column of air, confined in the bronchus either by a foreign body or by blood-clot, may be set in vibration by the cardiac contractions.

Captains Lockwood and Nixon, in a paper on the surgery of the chest, also deal with the fallacious character of signs suggesting injury to the pericardium. "The churning sound usually associated with hæmo-pericardium has been met with where this condition did not exist. A tumultuous and irregular heart beat has been met with when the pericardium has not been even penetrated. This phenomenon undoubtedly results when the heart has been hit by a large missile which rebounded, and which is seen by the X-rays to lie at some distance from the heart. Autopsy has revealed in two such cases severe bruising of the heart. The regularity of the heart beat is disturbed when the position of the missile is such that with each beat the posterior aspect of the heart touches the missile. A cardiac impulse visible with the X-ray is often imparted to a missile lying at some little distance without the pericardium and not in contact with the heart."

Colonel S. Maynard Smith also deals with the "tapping" phenomenon, under the title of pericardial knock. "It is of the nature of a click and varies from a faint sound, heard by careful auscultation, to a noise which may be compared to that heard in the ear-piece of a telephone when the lever is moved up and down. It may be heard sometimes when standing at the foot of the patient's bed. Sometimes the patient is conscious of it, and on one occasion has himself called my attention to it. The sound is, as a rule, most marked near the apex beat; it is usually double, corresponding with the heart sounds, and its intensity waxes and wanes with respiration, sometimes disappearing completely in full expiration. A distinct fremitus can be felt by the hand laid on the chest. In nearly every case the sound disappears after forty-eight hours; in one instance it persisted when the patient was evacuated at the end of ten days."

In one case a foreign body was visible on the screen in the cardiac area. It moved continuously with the heart beat, so that the skiagram showed only a blurred image. This patient died. At the autopsy the pericardial surface was normal. There was no infection, exudate, or any sign of pericarditis. The cavity contained a few drops of blood-tinged serum due to the passage of the missile, which had traversed the pericardium and lodged in the intraventricular septum.

Colonel Maynard Smith dismisses the suggestion that the sound is due to emphysema of the mediastinal tissue, but adds the following remark: "The usual disappearance of the sound after a short period and the absence of serious symptoms in

many cases suggest that it may be due to air in the interstitial connective tissue of the lung which is struck upon by the beats of the heart." His description of the character of the sound at once suggests the similar sound audible in the systemic vessels when they are seriously emptied by hæmorrhage and when the normal arterial tension is lowered; or again the "pistol shot" sound occurring in some arterio-venous communications recorded by Makins.

No doubt a considerable number of operations have been performed in which rents in the pericardium were repaired, or retained foreign bodies removed, but unfortunately few records of these are available. The following case, recorded by Major Scott Skirving, illustrates the nature of the symptoms caused by the presence of a foreign body in or near the pericardium, and also the methods of operation for their removal.

Case 7. A man, aged 22, received a wound in the posterior axillary line from a fragment of shell. Immediate severe shock resulted, the patient remaining unconscious for three days; he spat blood, and signs of pericarditis were noted.

Sixteen days later the man had recovered sufficiently to be sent from France to England, and after a period of rest in various hospitals he was returned to duty at the end of four months. As a result of deep-seated pain in the chest and shortness of breath on exertion, the man was then sent back to hospital. Apart from these troubles his general health was excellent. The pulse was small, rather soft, always fast (over 100), and occasionally missed a beat. The præcordial dullness was normal, a mitral bruit was audible, and there was very marked reduplication of the second sound especially in the pulmonary area. No pericardial friction was present.

X-ray examination showed a foreign body apparently situated about the upper level of the posterior reflexion of the pericardium to the left of the mid-line. Both vertical and horizontal movements occurred and were referred to pulmonary and cardiac excursions. It was inferred that the fragment of shell lay upon or between the pulmonary veins.

A chondro-plastic flap was raised, the pericardial cavity incised, and found more or less obliterated by soft, sticky blood-stained adhesions; the latter were freed by the finger and blunt dissection, the foreign body located and removed. It was thought that two-thirds of its bulk lay outside the confines of the sac against the pulmonary veins. No evidence of injury to the heart was detected. The piece of shell after its removal measured about $\frac{3}{4} \times 3\frac{1}{4}$ ins. The wound was closed completely, and the patient made an uninterrupted recovery. The necessary manipulation of the heart gave rise to no serious trouble.

That foreign bodies may remain enclosed in the pericardium for long periods without causing dangerous symptoms is an old observation; thus Delorme quotes the case of a Napoleonic veteran who lived fifty-two years with a round bullet fixed by adhesions in the pericardial sac, and whose only complaint was that he could not lie on the left side. Operations, however, have demonstrated the presence of adhesions, and dyspnœa

and rapidity of pulse on exertion have been sufficiently severe to call for operation.

A case recorded by Couteaud and Bellot is worthy of mention as illustrating a more serious sequence.

Case 8. A man was wounded from a distance of 1,500 metres; he felt a violent pain of a pricking character in the heart and fainted. He remained in a grave condition, with occasional hæmoptysis for some days. Later there was severe retro-sternal pain accompanied by intense headache, lasting for some hours. Gradual improvement followed, and in ten weeks the man was able to get about, but any effort gave rise to faintness and urgent dyspnœa. At the end of four months nothing abnormal could be discovered on physical examination of the heart, and the pulse-rate was 60, rising to 100 on exertion. An X-ray examination was made and a bullet was located in the position of the right auricle.

During the fifth month an acute myocarditis developed as evidenced by pyrexia, severe cardiac pain, signs of pericarditis, increase of cardiac dullness and disturbance of the cardiac rhythm by long pauses.

When the condition improved, operation was decided upon. Pericardial adhesions were encountered, and during the separation of these the patient became very pale, the action of the heart tumultuous and irregular, and the pulse imperceptible. During the necessary manipulation the auricular wall, friable from recent inflammation, ruptured, and the rent was repaired by suture. The bullet was then removed from a thick fibrous capsule without opening the cavity of the auricle. It lay just above the opening of the inferior cava in the posterior wall. The patient died on the second day after the operation.

Although described as a bullet lying in the wall of the auricle, it appears much more probable that the bullet wounded the surface of the heart only and became fixed in the fibrous capsule described as the result of pericardial adhesions.

Sir Berkeley Moynihan met with four cases of foreign bodies retained against or within the pericardial sac.

Case 9. Man, aged 21. Wounded by small fragment of shell entering the back over the left eleventh rib. The wound was followed by hæmoptysis continuing for three days, and cough with blood-stained sputum for seven or eight weeks. Six months later the heart sounds were normal, and no abnormal pulmonary signs were detected.

Shortness of breath, cough and pain over the heart were complained of. The third left rib was lifted, and the piece of metal was found adherent to the pericardium and lying just within the substance of the lung.

It was readily removed, and an uninterrupted convalescence followed. The man returned to active service seven months later and was demobilized after a further fifteen months. Two years later he reported himself as well but suffering from shortness of breath and headache if he undertook heavy work.

Case 10. Man, aged 25. X-ray report was made two and a half years after injury. Shrapnel ball lying to right of mid line. When viewed from the front it moved horizontally and transversely; viewed from the side the movement was antero-posterior. It moved downwards with the heart on inspiration. The fifth right rib was lifted, the pleura opened, and the adherent right lung was peeled from the pericardium until the ball was discovered surrounded by dense fibrous tissue. The ball was removed and the pleural sac closed by suture. A year and eight months later the man reported himself fit and doing his old work as well as ever.

Case 11. Man, aged 37. A bullet wound of the left chest was followed by cough, painful breathing and hæmoptysis for fourteen days. Six weeks later it was noted that the left lung was less voluminous than the right, but that the percussion note and vocal fremitus offered little more than physiological variation.

A bullet was visible on X-ray examination, which moved downward with inspiration, but not to the same extent as the diaphragm. A slight transverse movement accompanied the cardiac beat.

Two months after the injury was received the fifth left rib was lifted, the lung was peeled from the surface of the pericardium. The bullet was found imbedded in fatty fibrous tissue, adherent to the surface of the heart to the left of the apex and to a thickened pericardium. About half a drachm of pus was found within the bullet cavity ; the latter was swabbed out with pure carbolic acid and the wound closed. The bullet proved to be sterile on incubation for forty-eight hours.

Case 12. Man, aged 33. A year after receiving a wound of the chest the man was complaining of pain in the chest, and behind the sternum, especially on exertion. A shrapnel ball was localized behind the sternum. On X-ray examination the ball moved slightly downwards on inspiration, also synchronously with the heart's movements. The fifth right rib was lifted, the pericardium was cautiously penetrated, the ball was lifted from a fibrous sac with a gall-stone scoop, and the wound closed. An uneventful recovery followed.

Wounds of the Heart.

Most of the information that can be gathered from a perusal of the records of the war or from examination of the illustrative specimens collected might be gleaned from the classical literature on the subject scattered over some centuries. The feature of the surgery of the war as regards wounds of the heart is therefore a familiarity with conditions which were previously rare, and the evidence which is afforded that the treatment of injuries to the heart has now become a definite and promising field for the surgeon.

All the old series of statistics show an overwhelming proportion of ventricular as compared with auricular wounds, the frequency with which injuries to the chambers occur being in the order, right ventricle, left ventricle, right auricle, left auricle.

It is obvious that this distribution of the injuries corresponds with the relative degree to which the surface of the heart is exposed towards the front of the body, and to the relative size of the area presented by the external aspect of each chamber. It must also be borne in mind that a very large number of the older observations was made on the subjects of pistol wounds, either received in duels or self-inflicted, or on persons stabbed over the heart region. It is probable therefore that, if the numbers were revised in the light of the injuries of war, a larger proportion of wounds of the posterior and inferior aspects of the heart would be met with.

Published records and the War Office collection of specimens merely substantiate the greater frequency of ventricular injuries, and perhaps a larger number of cases in which both ventricles are implicated.

One other misleading feature should be mentioned. With the exception of four cases, all the specimens in the War Office collection were obtained from patients who survived the injury long enough to arrive in hospital and many of them lived several days. The four exceptions met with are as follows :—

(1) A wound of the right auricle, obtained by Lieutenant-Colonel Cowell as a result of an adventurous visit to " No-man's land " after a battle ;

(2) An extensive non-penetrating laceration of the ventricle obtained from the body of an aeroplane pilot whose machine " crashed " ;

(3) A self-inflicted rifle bullet injury ;

(4) A very extensive laceration of all four cavities of the heart caused by a fragment of high explosive shell.

In the first two of these instances death from shock is to be inferred ; in the third and fourth the extent of the damage amounted to actual destruction of the organ.

Nature of the Wounds of the Heart.—Wounds of the auricle as illustrated by the specimens in the War Office collection afford little scope for comment.

The wounds are either clean-cut perforations, slit-like apertures, or irregular lacerations corresponding in outline with the missile which caused them. As a rule, ecchymosis beneath the epicardium is slight or absent.

Fig. 3 shows well the nature of the openings, the remarkable feature of this specimen being the presence of three separate apertures differing little in size or shape.

The following cases are illustrative of auricular wounds :—

Case 13. (W.O.C.) A specimen removed from a man who was struck by a small fragment of shell over the ninth right rib. The patient was brought a distance of fifteen miles to a casualty clearing station, where the wound was explored and found to involve the diaphragm. The wound was excised, and the gap in the diaphragm closed by suture. Later on the same day death occurred.

At the autopsy the missile was found to have traversed the right auricle, and lodged in the pericardial sac in the pouch beneath the pulmonary artery. No record was kept of the amount of blood found in the pericardial sac after death. The openings in the auricle admit the passage of a glass rod 2 mm. in diameter.

Fig. 3.—Wound of auricle.

Case 14. (W.O.C.) This specimen was removed from the body of a man who died on the third day. When admitted to the casualty clearing station he was in a state of collapse. The fragment of shell entered the fourth right intercostal space 1 in. from the margin of the sternum. It perforated the anterior border of the lower lobe of the right lung, entered the right auricular appendix by an opening 2 mm. in diameter, and passing through the auriculo-ventricular opening, was arrested in the apex of the right ventricle.

Death resulted from purulent pericarditis, and at the autopsy an ante-mortem clot occupied the right auricle, extending through the tricuspid opening into the right ventricle, almost blocking the passage.

Case 15. (W.O.C.) A fragment of shell entered at the pectoral fold, fractured the third rib, passed through the upper lobe of the left lung, perforated the pericardium, and gave rise to a rounded laceration, admitting a pencil, of the wall of the left auricle at the base of the auricular appendix. After death the missile was found in the left pleural sac, which was full of blood. The missile therefore appears in passing to have perforated both the pericardium and the auricle without actually entering the sac. No record is furnished as to the date of death, nor as to the amount of blood found in the pericardium.

Case 16. (W.O.C.) A German soldier was wounded by a bullet which produced three rounded holes in the right auricle, each large enough to admit a pencil. Two ounces of fluid blood were found in the pericardium; the right ventricle was contracted and empty. The face was cyanosed. Lieut.-Colonel Cowell assumed the man died from pure shock.

Wounds of the ventricle are richly represented in the War Office collection, and are more varied in character than those of the auricle. One point may be emphasized as to these specimens as a series. In the vast majority the apertures are situated within the apical two-thirds of the ventricles, those that lie near the auriculo-ventricular groove are usually minimal in size, and no instance of a wound near the inter-auricular septum is included. It may fairly be assumed that no patient survived to reach a hospital who was struck near the main conducting strands for the cardiac impulse.

Of actual tissue destruction, every degree is met with. In some specimens bruising and sub-epicardial ecchymosis only are seen. Others show minute irregular slits, the only special character of which is a free epicardial margin surrounded by an area of sub-epicardial ecchymosis of from a line to half an inch in width. In a few instances, where a larger cardiac vessel has been implicated, the ecchymosis is more extensive.

The wound in the myocardium is more irregular than that in the more resistent epicardium. This is apparently due to the special structure of the heart muscle, the arrangement of which is more compact and complicated than that of the skeletal muscles. The larger wounds illustrate grossly the kind of damage which occurs. The bundles of muscle are torn and separated, giving a coarsely granular aspect to the wound.

These characters of the wounds give rise to difficulty in deciding by examination of the heart alone whether one has to deal with a wound or a rupture in any given instance.

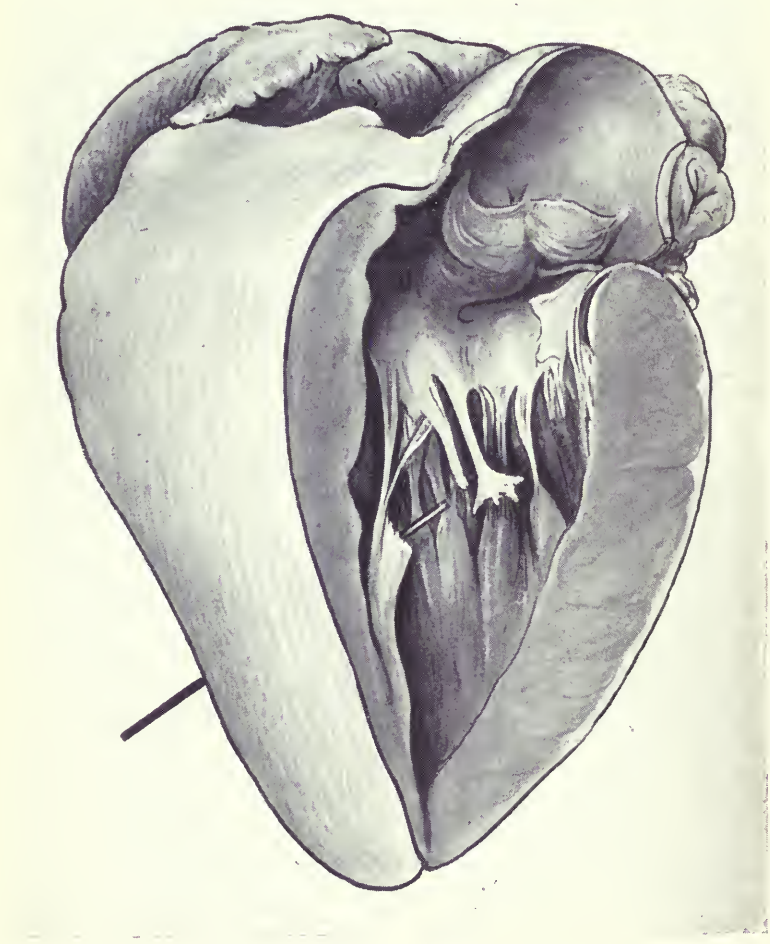

Fig. 4.—Wound of the papillary muscle.

Several specimens show some interesting details of the injury that may be inflicted within the cavities. One shows a papillary muscle wounded at its base, another a wound at the apex, while in that shown in Fig. 4, a small missile

which entered near the apex of the right ventricle has completely severed and set free one of the papillary muscles near its apex.

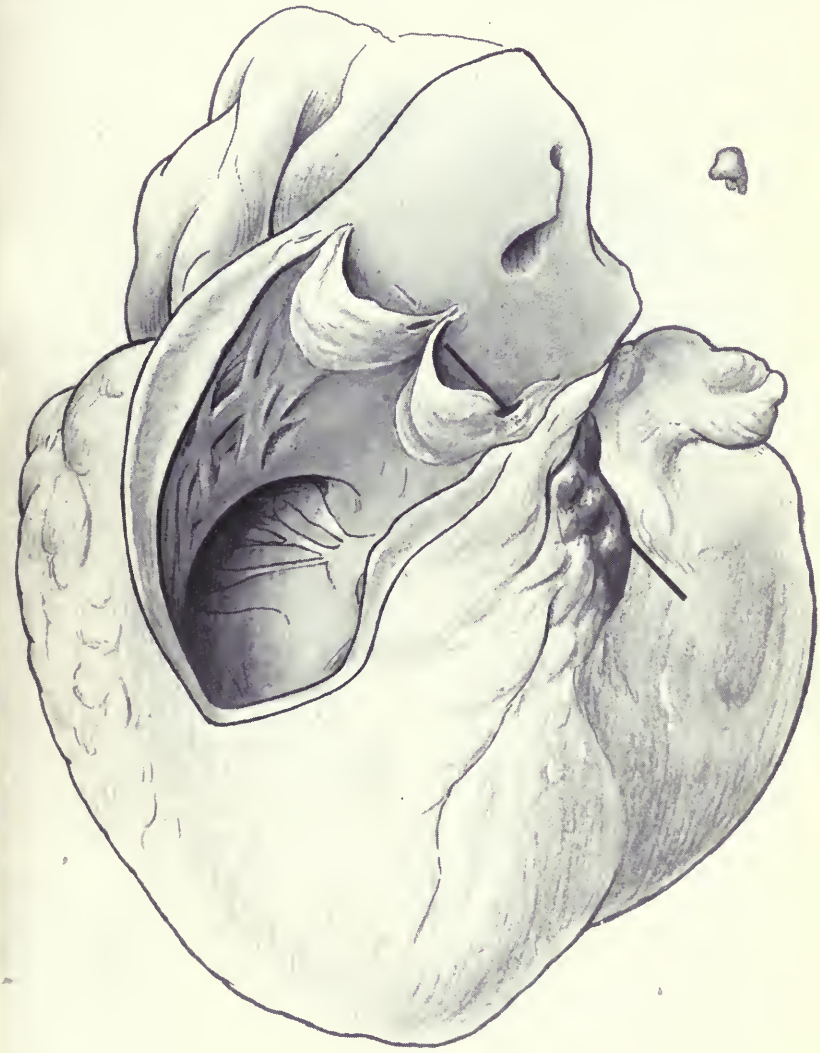

Fig. 5.—*Case* 17.

Case 17. In Fig. 5 (W.O.C.) an interesting valvular lesion is shown. A minute oblique track in the wall of the right ventricle, an inch and a half in length, is indicated on the surface by a patch of ecchymosis half an inch in width. The minute missile entered at the bottom of one of the sinuses of Valsalva, then made a small circular opening in the corresponding cusp of the semilunar valve, passed through a slit in the next segment of the valve near its margin and traversed the wall of the pulmonary artery, to become impacted in the space between the pulmonary artery and the aorta. The missile was a small fragment of a rifle bullet. The patient expired twenty minutes after receiving the injury.

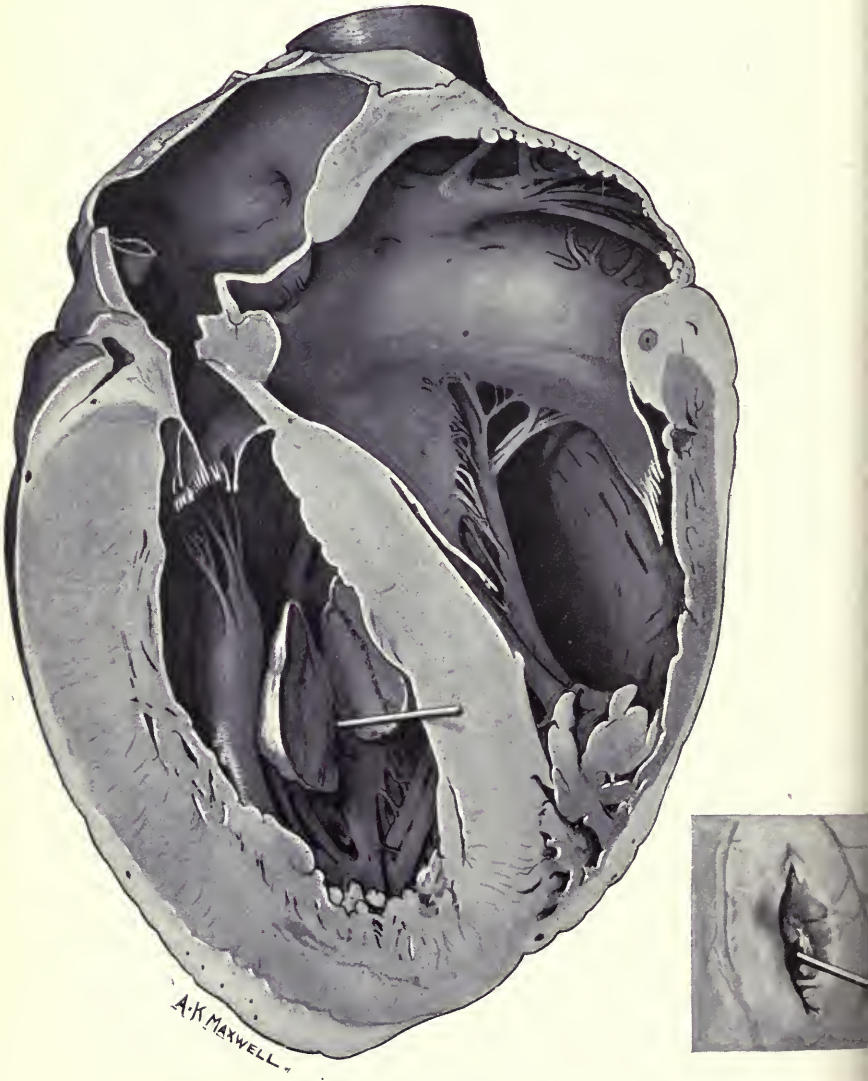

Fig. 6.—Wound of left ventricle.

Case 18. Fig. 6 (W.O.C.) illustrates an injury to the left ventricle of the heart. The specimen was obtained by Captain H. H. Henry, from a man who died shortly after admission to No. 13 General Hospital.

A grazing tangential wound caused by a small fragment of shell was present in the left mid-axillary line. Widespread ecchymosis extended to the mid-line anteriorly, and downward to the anterior abdominal wall. The fourth and fifth ribs were fractured in the left mid-axillary line, with some comminution. There was a laceration of the left lung, with a few patches of fibrinous clot about the base of the left pleura, and one or two ounces of free fluid blood in the pleural cavity. No wound was discoverable in the pericardium, but there was an infected linear wound (*see inset*) about three-quarters of an inch long on the anterior wall of the left ventricle. The area around the wound showed septic ecchymoses, and there was slight pericarditis. Within the cavity of the ventricle a firm fibrinous clot occupies the site of the wound, and is firmly attached. In the specimen it has been sectioned. No vegetations are to be seen on the mitral valve.

The right lung, the liver and the spleen were normal. Both kidneys showed septic infarcts, originating from the surface of the clot in the ventricle.

This specimen offers some difficult problems. The condition is readily explicable if one assumes the passage of a small fragment of shell from the left side of the chest through the lung to the cavity of the left ventricle, whence it was carried into the general circulation. In fact, no track was found in the thoracic parietes, nor any opening in the pericardium. Further, no evidence of a foreign body embolism is furnished. On the other hand, the wound in the heart was an infected one, which would seem to oppose the idea that it could be the result of a rupture. If the simple explanation be accepted, it must be assumed that the original track was rapidly obliterated.

The most remarkable remaining feature is that no hæmorrhage had occurred into the pericardium, and that the wound in the wall of the heart became blocked by clot, while an internal provisional thrombus formed, just as is the case in wounds of the large blood-vessels.

Case 19. (W.O.C.,) A similar ventricular lesion. In this case also a non-penetrating wound of the chest wall existed but was unaccompanied by any fracture of the ribs or sternum. A small slit-like aperture is seen in the anterior wall of the right ventricle, surrounded by a wide area of epicardial ecchymosis. In this instance the pericardial sac was distended with blood. The patient died shortly after the injury was received.

Case 20. A case of rupture of the anterior wall of the right ventricle, recorded by G. R. Turner and Leslie Pearce Gould, bears a remarkable resemblance to these two cases, but differs in that it was associated with a transverse fracture of the sternum caused by a fall of twenty feet from the deck of a ship on to a buoy.

When admitted to hospital an hour and a half after the injury, the patient was unconscious and signs of cerebral irritation were present. The radial pulse was impalpable and the heart sounds distant and feeble.

During the next few hours, consciousness was regained and complaint was made only of some abdominal pain. The heart sounds remained distant and feeble and the pulse impalpable. Death occurred suddenly with loss of consciousness, lividity, stertorous breathing, abnormal protrusion of the eyes, cyanosis, and intense engorgement of the head and neck.

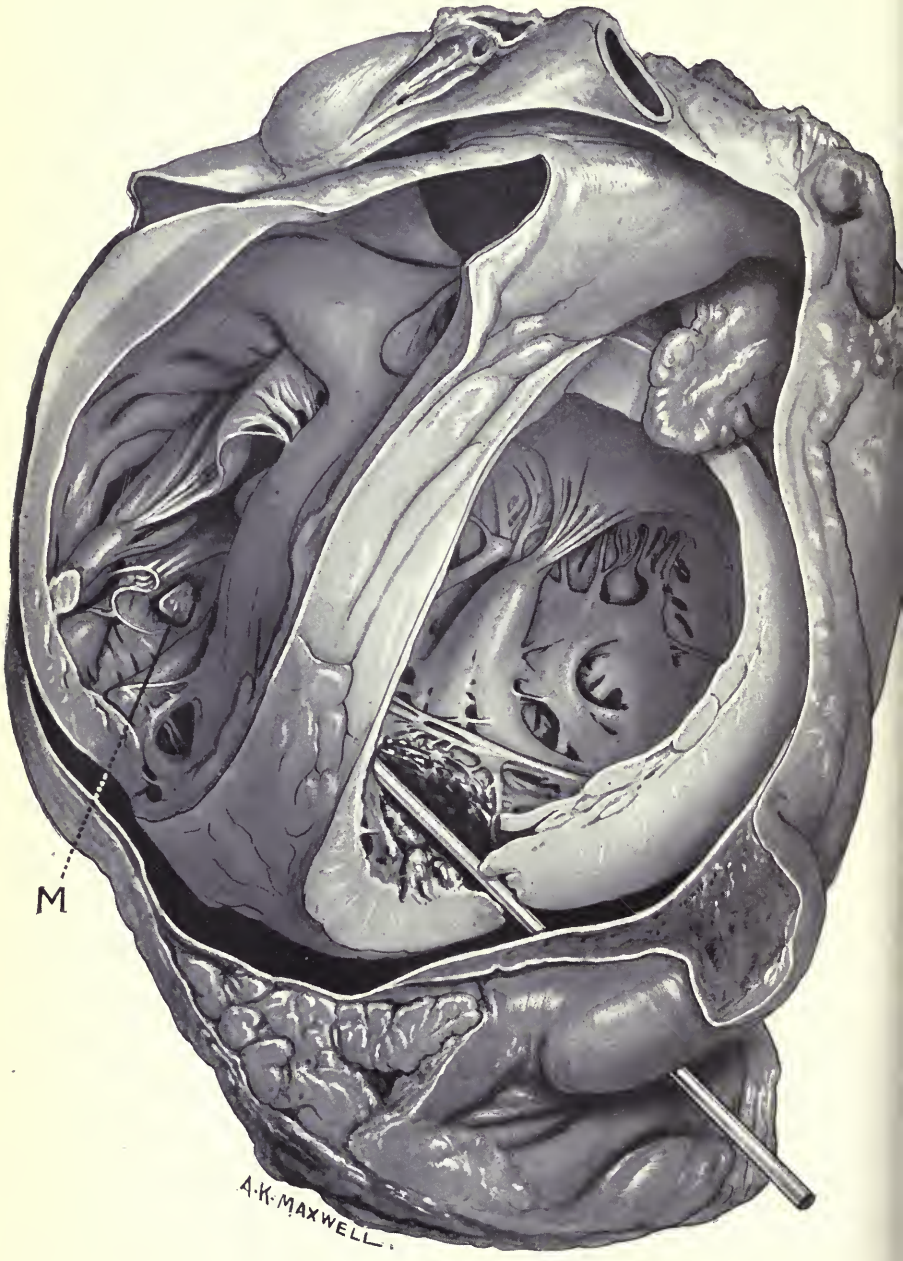

Fig. 7.—Traversing wound of ventricles.

At the autopsy an excess of cerebro-spinal fluid at the base, œdema and congestion of the cerebral veins were found, but no gross injury to skull or brain. The sternum was fractured, and the mediastinal tissue infiltrated with blood. The pericardium was bruised but intact; 15 ozs. of dark fluid blood occupied the sac. A rent large enough to admit a pencil was found in the anterior wall of the right ventricle, and the cavities of the right side of the heart appeared healthy. The authors state that up to the period of publication only 95 cases of traumatic rupture of the heart had been recorded.

Case 21 (W.O.C.) illustrates well the type of injury liable to be completely overlooked during life, one which would have probably given rise to no physical signs or symptoms, and might have healed completely. Except for the presence of the two small wounds the heart is normal. Unfortunately, the specimen is accompanied by no history except the statement that the injury was caused by fragments from a rifle grenade.

A small clean slit wound bounded by a narrow line of ecchymosis is seen at the highest part of the anterior surface of the right ventricle, while below a second missile has perforated the wall and entered the ventricle just above the apex. Both fragments must have been passed onwards into the pulmonary artery, but caused no serious lesion.

Case 22. Fig. 7 (W.O.C.) furnishes an example of a perforating wound of the heart caused by a small fragment of shell. The missile entered the thorax from the abdomen, perforated the wall of the left ventricle just above the apex, grooved deeply the posterior wall of the ventricle, wounding the root of one of the papillary muscles, and after traversing the interventricular septum is seen to be lodged amongst the columnæ carneæ of the right ventricle.

It is noteworthy that in this instance but little trace of fibrinous clot has formed on the exposed surface of the cardiac muscle.

Case 23. Fig. 8 (W.O.C.) affords a remarkable example of an infected wound of the heart. The patient was wounded at 10 p.m. and admitted on the following day into No. 17 Casualty Clearing Station, under the care of Captain R. Bertram Blair. Two small wounds were found in the left mid-axillary line over the fifth and sixth intercostal spaces respectively. There was also an aperture of entry in the left lumbar region, and two entry wounds were present in the upper third of the left thigh.

Physical examination revealed dullness extending to the left scapula, and pericardial friction. The right chest was normal. On the third day an examination with the fluorescent screen showed a foreign body with a "flail-like" movement, and also moving up and down with respiration, which was located to the chamber of the left ventricle. Half an hour after the man's return from the X-ray room the left lower extremity was noted to be blue and cold to above the level of the knee. The limb was raised upon a pillow, and after an interval of an hour regained its normal aspect.

On the fourth day the X-ray examination was repeated, and the foreign body which had been located in the left ventricle was now seen half an inch below, and to the left of the umbilicus, *i.e.*, at the point of bifurcation of the abdominal aorta. Nitrous oxide anæsthesia was induced, and fragments of shell were removed from the lumbar region and left thigh. The wounds were dirty and suggested early gas gangrene. The left pleura was aspirated and ten ounces of blood were drawn off. Cultures made from the blood proved negative. On the fifth day the man died from toxæmia, due to anaërobic infection, and fifteen hours after death an autopsy was performed.

At this time there was emphysema of the face and neck. A small quantity of blood was found in the left pleura and in the pericardium. There was a hole at the lower and back part of the pericardium, and a fibrinous exudate clothed its anterior and left lateral wall. The small aperture of entry in the posterior wall of the left ventricle was found, and a ragged laceration on the surface of the interventricular septum. A jagged tear of the apex of one of the papillary muscles was also seen. The myocardium was very pale and full of gas bubbles.

The foreign body was discovered at the bifurcation of the left common iliac artery, surrounded by dark-red blood-clot. The intima of neither the iliac artery nor the aorta had suffered any damage. A small hæmorrhagic infarct with indriven bone was found in the left lung, also apertures of entry and exit in the anterior portion of the lower lobe.

The illustration exhibits all these points. The infiltration of the myocardium with gas was no doubt a post-mortem development. The most striking features are the absence of any large quantity of blood in the pericardium, although the patient lived five days, and the passage into the left iliac vessels of the fragment of shell which caused the wound.

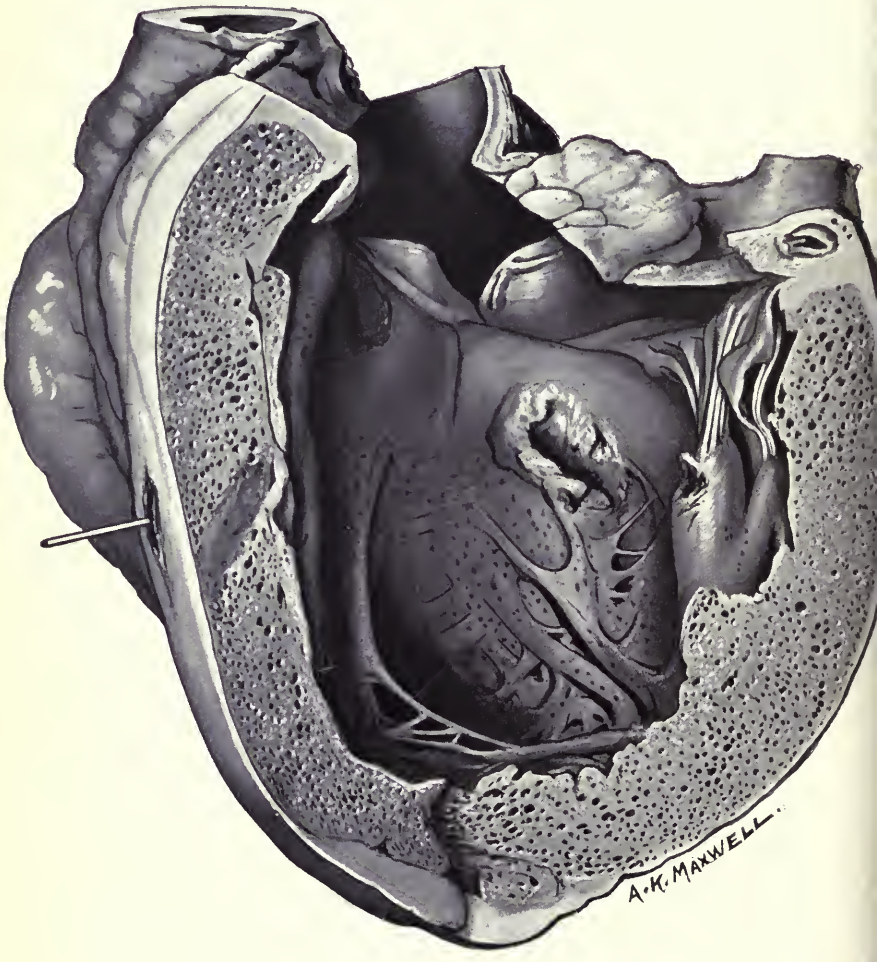

Fig. 8.—Gas infection of heart wall.

The next three specimens represent immediately fatal injuries, and illustrate the amount of destruction which the missiles of war are capable of producing.

Fig. 9.—Wound of ventricle.

Case 24. Fig. 9 (W.O.C.) is of the greatest interest. The patient, together with a second flying officer, was struck by armour-piercing bullets. Both were dead when the aeroplane reached the ground, but this heart was that of the pilot, and the fact that the machine was safely brought to a landing-place leads to the inference that in his case death was not immediate, in spite of the extent of the cardiac lesion.

The wound depicted is of the nature of an "explosive" aperture of exit. A deep crater not involving the cavity of the ventricles is exposed, the floor of which is formed by masses of separated bundles of the myocardium; in the upper part of the crater a dissected but uninjured branch of a large nutrient artery is exposed.

The aperture of entry lying just to the left of the inter-ventricular groove, about an inch and a half above the apex is irregularly rounded with a free margin of epicardium, and is separated by only a small strand of tissue from the exit wound, but it is not shown in the drawing. There is widespread epicardial ecchymosis.

Broken fragments of bullets found in the aeroplane suggest that the missile which caused the injury was a deformed fragment which resulted from a bullet first striking some portion of the machine.

Case 25. Fig. 10 (W.O.C.) depicts a specimen secured by Captain T. H. G. Shore at the camp at Etaples, and is an example of a self-inflicted wound. The muzzle of the rifle had been placed against the man's chest. The aperture of entry of the bullet, surrounded by an area of burned skin, was situated 3 ins. above the left costal margin, 1½ ins. within the left nipple line.

The bullet had traversed the heart, inflicted the injury depicted, and caused a large rent in the diaphragm through which the stomach was found prolapsed. The aorta was torn across immediately below the diaphragm, the left lobe of the liver was torn, and the bullet had injured the greater curvature of the stomach close to the œsophageal opening. The remaining abdominal viscera were uninjured. A little blood-clot was present in the left pleura, but the lung had escaped any damage. There were some hypertrophy of the left ventricle of the heart, and chronic nephritis of the type of the small white kidney. The aperture of exit, smaller than the entry wound and with everted edges, was situated in the right loin, 1½ ins. from the mid-line.

At the post-mortem examination the remaining portion of the apex of the heart was found displaced upwards by the herniated stomach. It is impossible to say whether the heart was struck in a state of systole or diastole, but the specimen is the only one which raises the question of hydraulic explosive effect.

Inspection of the specimen appears to show some signs of contusion of the broken margin of the right ventricle; otherwise the suggestion is of a more or less clean tear with radiating extensions, the widest of which is prolonged to the auriculo-ventricular groove. The comparison with the burst paper-bag inevitably arises, although the condition might be equally well produced by a combination of crushing and tearing, which would be in consonance with the expression "blown away," employed in the original description of the specimen, and would be the obvious explanation if the heart was struck during the period of contraction.

Case 26. Fig. 11 (W.O.C.) illustrates the extreme severity, and yet the localization of the injury, which may be produced by a large fragment of shell. The wall of all four chambers of the heart is seen to be reduced to tatters; yet the organ retains its general form and continuity.

The specimen was obtained from the body of a gunner who, while sitting on the limber close to the entrance to a casualty clearing station, was struck by a fragment of a shell which burst a few yards away from him. The missile traversed the sternum, damaged the heart as shown in the illustration, comminuted the vertebral column, and escaped from the back. The man fell in a pool of blood. The heart was removed shortly afterwards by Lieut.-Colonel E. M. Cowell.

Fig. 10.—Self-inflicted rifle bullet injury to the heart. The appearances suggest hydraulic explosive effect.

Fig. 11.—Extreme laceration of the heart caused by a fragment of high explosive shell.

A number of specimens in the War Office collection illustrate the retention of a foreign body either in the walls or within the cavities of the heart. Some have been already referred to, and others will be found under the heading of operations on the heart, but a few more typical examples may be added here.

Case 27. (W.O.C.) The specimen was removed from the body of a man who died on the ninth day after receiving multiple wounds. At the autopsy a small pellet of lead was found lying among the trabeculæ of the right auricle near the mouth of the auricular appendage. It was assumed that the missile had entered by way of the inferior vena cava. No cardiac symptoms had been observed during life, and the pericardium was normal.

Case 28. (W.O.C.) A small fragment of shrapnel case lying at the apex of the cavity of the right ventricle. The patient died on the tenth day after reception of multiple injuries, from "ileus," following an operation on the humerus. No cardiac symptoms are noted. The missile entered the heart from the inferior vena cava.

Case 29. (W.O.C.) A minute metallic fragment embedded in the interventricular septum. It entered the anterior wall of the right ventricle. Three ounces of blood were found in the pericardial sac. The patient died within twenty-four hours of reception of the injury as a result of grave abdominal lesions.

Case 30. (W.O.C.) A metallic fragment lying in a suppurating cavity in the substance of the wall of the right ventricle. The patient died three weeks after reception of the injury. Entry wound about six inches from middle line of back. Ninth right rib notched.

Case 31. (W.O.C.) A slit aperture is seen in the pericardium, and a fragment of shell is embedded in the wall of the left ventricle not impinging on the cavity. There is considerable mediastinal ecchymosis. The patient died on the ninth day from pericarditis; at the autopsy a thin purulent fluid occupied the sac, and suppuration had occurred in the retro-sternal blood effusion. A streptococcus infection of the knee-joint was also in progress.

Symptoms and Diagnosis.

The cases already detailed, and those included under the heading of treatment sufficiently illustrate the symptoms caused and the results which may follow gunshot injuries to the heart, but it may be well to summarize them briefly here.

It may be premised from the character of the injuries already described, and from the frequency with which the missile was retained in the heart itself, its near neighbourhood, or within the chest, that the cases which come under the care of the surgeon are those in which the heart is struck either by very minute missiles or by those travelling with low degrees of velocity.

The comparative infrequency of heart lesions amongst the large number of thoracic wounds also leads to the inference that a large proportion of the men struck in the heart dies either immediately from shock, or after a short period, from the collection of blood in the pericardium.

There is no reason to try and amplify the classical descriptions of such deaths. Many men die on the spot, some after a single exclamation, while others may spring forward and fall as if struck by lightning. More commonly still, the man falls in a state of extreme shock, recovers somewhat for a short interval, and then dies. Such cases are not likely ever to enter the sphere of practical surgery.

The more hopeful classes are those in which a slowly increasing collection of blood in the pericardial sac impedes the heart's action, those in which a retained missile gives rise to

cardiac symptoms, and those in which an infection is introduced by the missile and pericarditis set up. In all of these, successful results have been attained by surgical intervention.

Perusal of the cases recorded will afford information as to the course taken by these various classes, and at the same time indicate the many difficulties which arise in making a certain diagnosis of injury to the heart in men wounded on the field of battle. First with regard to the symptoms of shock, all the men are in the condition of mental tension common to those engaged in a fight; secondly, the instances in which the heart lesion is unaccompanied by other injuries are comparatively rare. Thus it will be observed that in many of the cases quoted the wounds were multiple, and often the injuries to other parts of the body or to other viscera were of the severest character. Then, again, the common association of pulmonary injuries is a very serious source of difficulty. Hæmoptysis and the collection of blood in the pleural sac with co-existing signs of shock and anæmia, dyspnœa and cyanosis are very apt to absorb the greater part of the surgeon's attention, and even a gross lesion of the heart may only be discovered on the post-mortem table. Further, there is ample evidence to show that perforation of the walls of the heart, and retention of missiles within its cavity may give rise to so little in the way of symptoms that the injuries may never even be suspected, and this the more so from the fact that the aperture by which the missile entered may be far away from the cardiac area.

With regard to the duration of the symptoms of shock, the histories show that some of the men say that they remained unconscious for a prolonged period after receiving the wound, yet some of them, after recovering consciousness, got up and walked considerable distances to an aid post or field ambulance. Others were brought into the casualty clearing station in a deeply shocked condition, and remained so for hours or days, and some of these on recovery travelled in ambulance cars or trains for long distances. Little aid, therefore, is likely to be obtained from this source in coming to a diagnosis.

A more fruitful source of information in patients suffering from cyanosis, dyspnœa, anæmia and small or irregular pulse, is to be found in auscultation and percussion. Such signs as friction or temporary friction followed by a gradual weakening of the strength of the cardiac sounds, accompanied with an increase in the area of præcordial dullness and

disappearance of a palpable apex beat, if constant and uncomplicated, would seem to make a diagnosis easy. It is well, therefore, to consider shortly the common difficulties which may arise. First of all a large accumulation of blood from a slowly leaking heart wound does not readily occur in a normal pericardium, on account of the resistance offered by the membrane; hence an effusion which is of too moderate amount to give rise to a large increase in the præcordial dullness may be exercising very serious compression on the heart. Then, again, the injury may be complicated by the presence of a large hæmothorax which renders the determination of the extent of cardiac dullness impracticable. Lastly, even signs such as a "mill sound" indicating a hæmo-pericardium may be due to an injury to the pericardium alone in association with a pulmonary wound. In such cases, moreover, the heart's action may be less interfered with as the pressure is not so great as when the track of the wound is too small to allow the escape of the blood.

An X-ray examination may give much help, especially in cases of hæmo-pneumo-pericardium, as in Case 6.

Case 32 (W.O.C.) furnishes an example of the difficulty which may be encountered in determining the source of the blood in a hæmothorax. A man was struck by a fragment of a rifle grenade which perforated the chest wall, crossed the reflection of the right pleura, penetrated the pericardium, entered the right ventricle just below the auricular ventricular groove, traversed the cavity and emerged on the anterior surface of the ventricle, the apertures of entry and exit being about an inch and a half apart. The missile then again perforated the pericardium and traversed the anterior margin of the left lung, causing a minimal amount of destruction.

The man was admitted cyanosed and dyspnœic. A double hæmothorax was diagnosed, and the heart sounds were noted to be normal. Death occurred 59½ hours later. At the autopsy the blood in the pleuræ was discovered to have come from the wound in the right ventricle, having leaked from the pericardium by the wounds on either side.

A second case may be quoted to emphasize this difficulty of diagnosis still more forcibly. It is perhaps even more instructive, since here there is a minimal injury to the heart and the injury is located in perhaps the safest and easiest region of the heart to deal with.

Case 33. (W.O.C.) The patient was wounded by a fragment of shell. On admission to a general hospital, he was suffering from a hæmothorax which became septic, and from which he died.

At the autopsy a hæmo-pericardium was discovered, the source of which was a "pin's head" opening in the posterior left ventricular vein. The heart was normal except for an extensive sub-epicardial hæmorrhage, which rendered some four-fifths of the surface of the ventricles dusky in colour.

Some further difficulties and peculiarities associated with auscultation have been already referred to under the heading of injuries to the pericardium.

The diagnosis of pericardial effusion as a result of infection is a less difficult problem, the most important point perhaps to keep in mind being the tendency in such gross infections to the early formation of adhesions within the pericardial sac, and as a consequence, the tendency for fluid collections to occupy the deeper part of the cavity, and hence not to lead to a wide increase in præcordial dullness.

For the determination of the presence of retained foreign bodies either in the neighbourhood of the heart, within the pericardium, the substance of the walls of the heart or the cavity, an X-ray examination furnishes a ready and certain aid. Yet as the numerous cases described show, the exact localization in one or other of these positions is not always easy, and may only be determined at the time of operation. Further, a perusal of published cases cannot fail to emphasize the insignificant nature of the primary symptoms in a large number of instances, so that no X-ray examination seemed to be called for until a comparatively late date, when the patients had attempted to resume their usual occupation or had been returned to active service.

The signs which indicated the advisability of X-ray examination and later the removal of the foreign body seem to have been consistent and regular in character. In every case there was noted a pulse rising in frequency and sometimes becoming irregular in rhythm on exertion, accompanied by a varying degree of dyspnœa. Less constant but common were the existence of fixed local pain, behind the sternum or " deep in " the chest, and sometimes inability to lie in certain positions without pain or discomfort. It is noteworthy, moreover, that these symptoms are more marked when the foreign body lies in close proximity to the heart, or even without the confines of the pericardium, than when located in the walls or still more when within the cavities.

With regard to foreign bodies within the cavities, little is known except that the general tendency is for them to be passed on into either the general or the pulmonary circulation. A number of instances of retained fragments of shells has been quoted, the most common site being the apex of the right ventricle, amongst the fleshy columns of the heart muscle. In one case only was the missile retained in the right auricle, and there amongst the muscular columns at the opening into the auricular appendage. It must be remembered that all these records are of fatal cases, and the hearts were removed from patients who

had been in a more or less recumbent position from the time of the reception of their wounds. The practical significance of the retained foreign body is twofold, in the early stages as a cause of infection usually giving rise to pericarditis, in one of the cases recorded to an abscess in the wall of the ventricle ; in the later stages as causing disturbances of the heart's action. It is noteworthy that in one of Sir Berkeley Moynihan's cases an abscess in connection with an obsolete infection was met with as late as two months after the entry of the missile.

The two specimens illustrating gross damage to the valvular mechanism of the heart were obtained from men who died shortly after receiving the injury, and it may be assumed that this is the ordinary course of events.

Surgical Operations on the Heart

In the small series of cases quoted below a considerable variety of operative methods is disclosed, but these by no means represent the degree of development which cardiac surgery has now reached, and for which we are in considerable measure indebted to French surgeons.

It will be convenient, therefore, to preface the clinical records with a short survey of the objects to be attained and the methods which, up till the present time, are most suitable for their realization.

The objects may be shortly enumerated as follows :—

(1) Closure of a rent in the pericardial sac.
(2) Closure of a rent involving both the pericardial and pleural cavities.
(3) Drainage of the pericardial sac.
(4) Repair of a wound in the heart.
(5) Removal of foreign bodies from (*a*) the neighbourhood of the heart, (*b*) the pericardium, (*c*) the wall of the heart, (*d*) one of the cavities of the heart.

Closure of Rents in the Pericardium.—It must be comparatively rare for a formal operation to be indicated. The apertures produced by small missiles are negligible in the absence of serious cardiac complication ; and, where the rent is in association with a serious fracture of the ribs, costal cartilages or sternum, enlargement or adaptation of the existing wound of the chest wall is the natural procedure prior to closing the aperture in the pericardium by suture.

The closure of pleuro-pericardial rents will also be effected as a rule by an incision localized by an existing wound. The

procedure is most likely to be indicated by a condition of hæmo-pneumo-pericardium.

Drainage of the Pericardium.—Cases in which simple drainage of the pericardium is required in military surgery are rare. Sir G. H. Makins twice performed this operation in France, on one occasion successfully, for the drainage of pus resulting from a general infection. In each instance the operation consisted in resection of the sixth and seventh costal cartilages. Littler Jones' case, recorded on p. 436, is an example of a more common form of operation in military surgery. In that instance, portions of the 5th, 6th and 7th costal cartilages and half of the width of the corresponding portion of the sternum were removed. An operation of this class, or one following the type lines set out in the next paragraph, must often be necessary in gunshot injuries, for it is rare that pericardial adhesions will not have to be dealt with, and an infective foreign body may often have to be located and removed. Further, an unsuspected lesion of the heart may have to be treated. For all these reasons a free exposure is necessary, and where septic infection is present, no form of chondro- or osteo-plastic flap is permissible.

The maintenance of drainage after a free anterior incision is aided by the fact that the constant movements of the heart tend to extrude pus collecting in the sac ; in fact, the conditions are not unlike those in which it is sought to keep the suppurating knee joint free from stagnant pus by instituting early active and passive movement. Nevertheless, pus does tend to collect and stagnate in the pouches at the back of the heart, and it may be found necessary, as in Littler Jones' case, to irrigate this portion of the pericardial sac at least once daily. In that instance also the tendency to the formation of large masses of lymph, which could not escape by any tube, illustrates the advantage of a free anterior opening. Sir Charles Ballance has suggested a left lateral opening to drain the pouch or bursal sac occupied by the left auricular appendage.

For drainage and irrigation of an infected pericardium, no method is better than that of Carrel, since larger tubes are cumbrous, uncomfortable and inefficient, while wicks of gauze form but a poor substitute for the smooth shining soft surface upon which the heart is accustomed to act. If any form of wick is employed, it should be of sheet rubber.

Repair of Wounds of the Heart.—Free exposure and sufficient space for untrammelled manipulation of the organ are essential conditions for the rapid procedure needed. On the other hand,

as it must be assumed that in the overwhelming majority of instances a non-infected wound has to be dealt with, methods preserving the bony framework of the chest are to be preferred. In the rare event of an operation for wound being performed through an infected pericardium, the surgeon will do well to resect ribs and cartilages and leave a wide opening for drainage. This question arises later in considering operations for the removal of retained missiles.

Three types of operation comply with these requirements.

(1) A Flap Method.—A vertical incision over the centre of the sternum is carried from the level of the junction of the third costal cartilages downwards to that of the sixth. From the upper extremity the incision is then prolonged to the left in the line of the third cartilage, and from the lower extremity along the sixth.

A musculo-cutaneous flap is raised and turned outwards exposing the fourth, fifth and sixth cartilages.

These three cartilages are then resected, a sufficient length being taken to ensure a proper exposure of the front of the heart. The mediastinum is now exposed, the internal mammary artery ligatured, the triangularis sterni set free and the margin of the left pleura is displaced outwards by gauze stripping so as to bare the anterior of the pericardium.

An angular incision is made in the pericardium following the left margin of the sternum and prolonged in the line of the sixth costal cartilage. It may be most conveniently commenced opposite the lowermost point of the margin of the sternum, and carried upwards and then along the line of the sixth cartilage to the apex of the pericardial sac.

(2) A Spanning Method.—An incision is made over the fourth or fifth intercostal space commencing at mid-sternum and prolonged to the left to a sufficient extent; the incision is carried down to the space and the inter-costal muscle divided.

A rib retractor is now inserted and the space widened. The degrees to which the breach thus established in the chest wall of the living subject may be widened is, according to Sir Berkeley Moynihan, as follows:—"A simple incision of one intercostal space permits separation of the ribs by about 6 cm.; further division of the cartilage above or below permits of a separation of 8 cm.; division of both cartilages together gives an opening of about 12 cm., and the supplementary division of the third cartilage enables the separation to be enlarged to 19 cm."

The mediastium being thus exposed the pericardium is bared and opened as in the flap method.

(3) Duval and Barnsby's Method.—An incision commenced at the level of the junction of the third costal cartilages with the sternum, is carried down in the mid-line to a point halfway between the xiphoid cartilage and the umbilicus.

The muscles attached to the xiphoid are divided, and two fingers are carefully inserted to separate the pericardium and pleura from the back of the sternum.

The sternum is divided transversely opposite the third cartilages, and the gladiolus below and the xiphoid are split in the median line.

The peritoneal cavity is now opened and also the pericardium in the median line. The heart is gently displaced upwards and the diaphragm is divided as far backwards as the coronary ligament by a pair of scissors one blade of which lies within the pericardial sac, the other in the abdomen.

The two halves of the sternum are widely separated by a retractor and the whole pericardial cavity is exposed.

The heart having been exposed by one of these methods, the first step consists in securing adequate fixation and control of the organ by the passage of a silk thread through the muscle of the apex. Either surface of the heart may thus be brought into view and maintained in position for the passage of sutures.

The closure of non-penetrating wounds may prove a simple matter, unless complicated by hæmorrhage from one of the large branches of the coronary arteries.

In the case of penetrating wounds the procedure may be one occasioning great anxiety and difficulty. Fortunately the heart is remarkably tolerant of manipulation, a fact which has been observed by all operators, and it has generally been found practicable to effect provisional hæmostasis either by compressing the margins of the wound together locally or by placing the finger in the gap. If local pressure fails the whole organ must be grasped and compressed above the level of the wound.

When blood is escaping from the wound, the flow is often intermittent, but it may gush freely. In some instances, moreover, the intermittent gushes may be synchronous with inspiration and not with the cardiac contraction, as in Case 35 below. On the other hand, a penetrating wound may not bleed at all, as in Case 18, and may be readily sutured. In cases in which a recent small penetrating wound has ceased to bleed and is difficult of location, Sir John Bland-Sutton points out that gentle compression of the great vessels at the root of the heart may be useful in helping to discover the leaking spot.

Sutures are passed through the wall of the heart *en masse*, care being taken to avoid exposure of the deep part of the stitch in the cavity of the organ. In some cases some more superficial stitches have been added to effect complete hæmostasis. Care should be taken not to draw the stitches so tightly as either to tear the myocardium or to effect eventual tissue necrosis. The frequent observation of spontaneous cessation of haemorrhage from wounds of the heart shows clearly that accurate apposition with a very small degree of pressure is all that is needed for a safe closure.

When the wound in the heart has been dealt with the pericardial sac should be irrigated and closed by suture. Given a non-infected wound, the question of drainage should not arise, but it may be emphasized that these operations are of a class in which the most meticulous care in technique is necessary and essential to success. An irregular cavity with pouches and recesses is opened up for the reception of any gregarious microbe, cut bone surfaces are exposed, and delicate manipulations need to be carried out in a restricted area; moreover, and this perhaps is the most important point of all, rapidity of action may be required at a crucial moment of the procedure. This is a subject for preparatory reflection on the part of the military surgeon who at any moment on active service may be called upon for the first time in his life to deal with a wounded heart. It is unnecessary to enter into any further detail with regard to the closure of the wound in the thoracic wall made to expose the heart.

Removal of Foreign Bodies.—When the foreign body is actually located in the wall of the heart, or in one of its cavities, one of the methods of exposure already described should be chosen.

With regard to variations in technique in operations undertaken with this object, it may be pointed out that in dealing with a foreign body impacted in the wall it should be assumed that penetration is always possible, and precautionary suture threads should be inserted, passing deeply to the missile before making any attempt to extract it. Perusal of Sir Charles Ballance's case (Case 36) will furnish information upon this subject, and also afford detailed information as to compression of the heart for the restraint of hæmorrhage.

The cases of removal of metallic fragments from the cardiac region and the pericardial sac by Sir Berkeley Moynihan (Cases 9, 10, 11, 12, and 39) show that a very much more limited interference with the bony framework of the chest

than is recommended in operations for exposure of the heart may often suffice for this object.

The procedure adopted by him is a slight modification of Duval's operation for the removal of foreign bodies from the lung.

An incision is made in the line of a rib and costal cartilage, usually the fourth or fifth, starting at the margin of the sternum and carried outwards over the centre of the rib and following its curve for about five inches.

The primary incision divides skin, subcutaneous tissue and the pectoral fascia. A pair of forceps is pushed between the fibres of the pectoralis major to the under-lying rib, and the fibres of the muscle are separated for the whole length of the incision. The pectoralis minor is then treated in similar fashion. All bleeding vessels are ligatured.

Incisions are carried through the periosteum of the exposed rib along its upper and lower borders and from these the rib is separated from the periosteum on the deep aspect. A periosteal elevator is passed beneath the rib and the bone is cleared for the whole length of five inches.

The medial end of the costal cartilage is divided by two incisions meeting at a point, so that when it needs to be replaced, the pointed extremity dovetails into a V.

The rib is lifted by a gauze loop, and drawn outwards; in young subjects the elasticity is sufficient to allow the rib to be drawn well out of the way of the operator's hand. If the rib fractures, it may still be safely replaced at the termination of the operation.

The posterior periosteum and subjacent pleura are now incised, a small opening only being made in order to favour a slow gradual collapse of the lung. The incision in the periosteum and pleura is then lengthened sufficiently to allow the passage of the whole hand, and the rib spreader is introduced.*

Adhesions are now dealt with and the lung freed. The adhesions may be readily separated by "gauze stripping" in some cases; in others, the use of scissors is necessary as the adhesions may be firm and strong, even like layers of thick felt.

Old blood-containing cavities or obsolete empyemata have been met with in operating for the removal of foreign bodies from the lung. If hæmorrhage is free from the torn adhesions, pressure by hot moist swabs suffices to control it.

* Sir Berkeley Moynihan recommends Tuffier's pattern, and says he has never found it necessary to divide additional cartilages and ribs.

When the region occupied by the foreign body is exposed, the latter is felt for by the finger, and any structures which cover it are divided. It may then be removed by a forceps or a scoop.

The wound is closed in layers. The incision in the periosteum is closed by suture. This may be difficult, but is facilitated by passing a strong stitch round the ribs above and below the incision and dragging them closely together.

The costal cartilage when replaced is fixed in position by a single catgut stitch. Lastly the pectoral muscles, the pectoral fascia and the subcutaneous fascia and skin are successively sutured.*

The following cases, most of them culled from published records, indicate some of the signs upon the strength of which operations on the heart have been undertaken. It is noteworthy that in no instance has an operation been decided upon simply on the ground of the position of the wound or wounds. This must be regarded as a sound precedent. Consideration of the cases shows the chief sin of omission to have been in connection with the disregard of impacted foreign bodies, and places in strong relief the fact that the chief secondary cause of mortality is infection. Accumulated experience tends to show that, if many of these cases had been treated more radically, infection and consequent pericarditis might not have assumed so prominent a rôle.

The records are meagre and there is little doubt that operations on the heart were more frequent than the publication of cases would lead one to suspect, but it has not proved possible to trace any more.

The following cases are placed in the order of publication :—

Case 34. (Reported by Birkbeck, Lorimer and Gray.) The man was admitted to a general hospital eight days after receiving a bullet wound. He was knocked down, but did not lose consciousness, and had no discomfort other than slight pain in the wound.

A small dirty entry wound half an inch in diameter lay just below and to the right of the xiphi-sternal articulation. Except for a painful swelling of the right parotid gland, which disappeared the next day, there were no further symptoms. Heart normal and regular, pulse 80–90. Evening temperature 100°–101° F. The man was kept in bed.

An X-ray examination made upon the tenth day showed some slight increase of the cardiac shadow on the right side. In the lower part of the heart shadow was a very sharply defined darker area which moved with the heart, and also " apparently laterally in relation to the heart." The latter movement suggested that the object was free in the pericardial cavity, but on

* The description of the operation in greater detail will be found in Sir Berkeley Moynihan's article on Surgery of the Chest in Relation to Retained Projectiles. (*See* Bibliography.)

turning the patient over it was seen to lie quite definitely in the substance of the heart. It had a distinct rocking movement, but no antero-posterior movement was visible in relation to the heart. The object was located as in or close to the lowest portion of the right ventricle, and it appeared to be a rifle bullet.

On the fourteenth day the patient suffered from a sharp pain in the left leg, and during the next night irregularity in the pulse-rate (65–95), and occasional dropped beats were noted. Colonel Gray now decided upon an operation which was performed on the fifteenth day.

Local anæsthesia was induced, (eucain 1 per cent., potass. sulph. ½ per cent., and adrenalin), and Colonel Gray made a horseshoe incision, convexity upwards, which extended along the sixth costal cartilage on each side and crossed the sternum at the level of attachment of the fifth costal cartilages. The incision was planned to expose the deep part of the original wound track. The left sixth costal cartilage was freed from perichondrium, and cut across at the costo-chondral junction; it was then used as a lever to elevate the sternum, while the triangularis sterni and pericardium were separated from the posterior aspect of the flap. The sternum was divided transversely at the level of the fifth costal cartilage, and the osteo-plastic flap was turned downwards. This disclosed a hole in the right pleura made by the bullet, and the right lung collapsed. Respirations became laboured and quick, the patient coughed jerkily, became anxious and complained of breathlessness. The colour remained good and the patient settled down in about a minute after being reassured by the surgeon.

The pericardium was opened obliquely in its whole length, about a drachm of blood-stained fluid lay in the cavity, the heart looked normal. Digital examination located the bullet at the back of the heart either in the wall or within the cavity of the right ventricle near the apex. During the manipulation the heart was noted to miss a beat occasionally when touched at the upper and back part of the interventricular septum. A suture was passed through the muscle of the heart near the apex, and the organ held forward. A needle was now passed into contact with the bullet, its mobility within the heart was determined, and by manipulation, it was worked away as far as possible from the line of the coronary vessels and fixed by a grip of finger and thumb. Two stitches were passed through the muscle over the position of the bullet, a half inch incision was made, the bullet exposed and removed with a forceps. The wall of the ventricle was throughout grasped until the two stitches were tied. Subsequent brisk bleeding was controlled by an under-running stitch, the pericardial cavity was wiped free of blood-clot, filled with normal saline solution, and closed by suture.

The right pleura was filled with saline solution and sewn up. While the external wound was being closed the pleura was aspirated to remove the saline, and this was the only part of the operation which caused pain.

Four hours after the operation the respirations rose to 48, and practically remained at that level until the patient's death on the fifth day after operation. During this time, accumulation of mucus in the throat and trachea caused much trouble. There was no indication that the operation on the heart had interfered with its action; the pulse, though quick (120–130), remained wonderfully strong up to within a few hours of death, and no dropping of beats was noticed.

At the autopsy, the external wound had healed well, and there were no signs of inflammation. The heart was covered with a shaggy layer of lymph, one-sixth of an inch thick; there was no exudation of blood or pus in the pericardial cavity. (W.O.C.)

Ante-mortem clots were entangled amongst the chordæ tendinæ of the right ventricle, and a long narrow clot was found in the pulmonary artery, extending into its right branch. An abrasion of the endocardium marked the spot in the right ventricle at which the bullet had lain, but the cavity looked normal otherwise. No aperture of entry was discovered.

Two pints of blood-stained serous fluid were found in the right pleural cavity, and there were several small clots in the branches of the pulmonary artery with corresponding infarct areas in the lungs. The right lung was expanded about two thirds.

Death was attributed to multiple pulmonary infarction from clots derived from the right ventricle.

Gray calls attention to the successful local anæsthesia, the evanescent nature of the distress when the right lung collapsed, the absolute absence of sensation in the pericardium, the difficulty of exactly localizing the bullet, and the method adopted to obtain rapid distension of the lung.

Case 35. (Reported by Captain John Fraser.) Fraser had observed two patients who died from accumulation of blood in the pericardial sac, in from six to eight hours after admission into a casualty clearing station. Case 35 was a third case upon which he operated.

The patient was the subject of multiple wounds; face, both eyes, arms and chest. The man was admitted in fair condition, with no intense shock, there was slight general cyanosis, the pulse was variable in rate averaging 100, the beat was irregular, and the amplitude small with an occasional stronger beat.

The heart was exposed by an incision from the centre of the sternum, prolonged over the sixth costal cartilage and the first inch of the rib. The fifth costal cartilage was isolated, and its sternal end divided. The opening in the chest wall was then spanned. When the mediastinum was exposed, the internal mammary artery was ligatured, and the left pleural reflexion separated laterally.

Blood now escaped from a perforation in the pericardium, the latter was incised obliquely and the heart exposed. Free blood was removed, and an extensive sub-epicardial hæmorrhage was seen extending along the auricular ventricular septum, and a small valvular perforation passing upwards and inwards for an eighth of an inch in the anterior wall of the right auricle.

Blood escaped from the opening at each inspiration rather than during the cardiac cycle. A traction suture was introduced into the wall of the heart to bring the organ well into the operation wound. Two mattress sutures so introduced as to evert the edges of the perforation were inserted and tied. A rubber drain was left in the pericardium, and the wound was otherwise closed.

The patient made uninterrupted progress. When seen four months later he was in perfect health.

Case 36. (Reported by White and Ballance.) A trooper, aged 21, was wounded by a bullet, but rode several miles to the nearest dressing station where he collapsed. It was noted that the bullet after traversing the right arm, had entered the right fourth intercostal space and had not emerged. A radiogram taken the next day showed the bullet two inches from the surface of the chest on a level with the interior border of the heart, moving with the cardiac pulsations.

Two months later when he arrived at Malta, the man's general condition was good. The pulse when the patient was lying down was 96, steady and regular; on exertion, as on getting out of bed or picking up an object off the floor from the bed, it became rapid and irregular. X-ray examination showed the bullet lying behind the fifth left costal cartilage and fifth interspace three-quarters of an inch from the sternal margin and two inches from the body surface. During the voyage from Salonika he had suffered severely from sea-sickness and this had caused much distress from palpitation and choking sensations. An exploration was decided upon one month later. The Delorme-Kocher incision was made, the fourth, fifth and sixth costal cartilages removed, the pericardium exposed and opened. A very little gas and frothy fluid escaped and no adhesions were found. The bullet was located by palpation through the posterior wall of the right ventricle near the apex.

Fixation stitches were passed close to the apex of the heart along the anterior interventricular groove; by means of these the apex was drawn upward and forward, and thus exposed the posterior surface of the heart. No scar was visible, but the bullet was felt on the right side of the posterior interventricular groove. Four silk stitches, passed twice through the muscle so that the loops could be drawn out of the way, were then introduced along the line of the proposed incision. The heart was seized with the left hand by one of the operators, using the thumb to compress the right ventricle above the line of incision. An opening was then made by the second operator, and the first introduced a pair of artery forceps, seized the bullet and pulled the free extremity outside the heart. A further incision was needed to free the remainder of the bullet from its bed in the ventricular wall. Fairly profuse hæmorrhage was at once checked by tightening the stitches already introduced, and the closure was reinforced by four more, put in Lembert-wise to invert the outer wall of the ventricle. The manipulation caused little distress to the heart, and the pulse only failed momentarily during the escape of blood. Saline solution was left in the pericardium which was stitched up, and lastly the skin was sutured.

There was no shock, and for the first few days progress was good. Signs of infection then appeared, free discharge from the wound commenced, and the man slowly lost ground and died one month later. At the autopsy the pericardium was found to be lined by a thick adventitious membrane, the visceral layer was intact but thickened, and some petechial hæmorrhages were seen. The line of incision at the back of the right ventricle was not visible, but two or three puckers on the surface of the heart gave some indication of the site of the operation.

Case 37. (Reported by Captain W. Briggs.) (W.O.C.) The man was wounded by a bullet which, entering in the right posterior axillary line, was located by the X-rays as lying one inch above the cardiac apex. A right hæmothorax ensued; this was aspirated, and sterile blood was evacuated. Later, rigors occurred and pericarditis was diagnosed.

On the ninth day after reception of the wound a chondro-plastic flap involving the 4th, 5th and 6th costal cartilages was raised, the pericardium was incised, two ounces of flaky serum evacuated, and a bullet was removed from the wall of the heart.

Death took place eight hours later. The specimen in the War Office collection shows evidence of severe pericarditis. The bullet has been replaced in its original position in the wall of the ventricle.

Case 38. (Reported by Major H. H. Sampson.) The patient had a bullet removed from a wound in the chest wall, and was then sent on to a casualty clearing station with the diagnosis of a penetrating gunshot wound.

On examination there was an entrance wound the size of a two-shilling piece on the left side of the chest outside the nipple line at the level of the sixth rib. There was a similar exit wound just to the left of the middle line at the level of the third costal cartilage. From this wound a shell fragment had been removed at the field ambulance.

The tissues intervening between the wounds flapped in and out during respiration, and there was some leakage of air through the external wound.

The usual signs of shock were present, but the general condition was fairly good.

An operation was performed as soon as possible after admission. The entrance and exit wounds were excised and then joined up by an incision through the superficial tissues. The intervening ribs and costal cartilages had all been fractured, and portions of cartilage had been carried away. The splintered ends were cut off, giving a good exposure.

There was a wound through the thin anterior part of the left lung, and a hæmothorax of moderate size was present.

There was a single linear tear in the pericardium measuring one and a half inches in length, and subjacent to this a similar gutter wound in the left ventricle of the heart. The wound of the ventricle was gaping widely and was

half an inch deep at its centre, where there was a small firm blood clot, around which blood oozed at each ventricular contraction.

Without disturbing the clot, the left ventricle was stitched with interrupted catgut sutures on a round curved needle, the needle being entered half an inch from the edges and passing down to the bottom of the wound.

The pericardium was washed out with weak Dakin's fluid, dried out and closed completely with a continuous buttonhole catgut suture.

The pleura was similarly washed out and dried. Spirit and B.I.P. in succession were applied to the wound, and the pleural cavity was closed by an air-tight suture of muscle. The skin wound was then sutured without drain. The wound healed by first intention. The patient was evacuated by train to the base ten days later, and was ultimately discharged from hospital on 4th April, 1919.

This case is one that illustrates well one of the advantages which accompanied the later practice of primarily closing wounds of the chest.

Case 39. (Reported by Sir Berkeley Moynihan.) A man was admitted one year after receiving a wound in the left mid-axillary line from a shrapnel ball. The injury was followed by short and painful breathing but no hæmoptysis was remembered. An empyema formed, was opened on the ninth day, and continued to discharge for six months. The original wound continued open and discharging throughout. The man still complained of shortness of breath on exertion. No pain or cough. There was evidence that the wounded lung had not re-expanded.

An X-ray examination showed the retained ball lying between the auricle and ventricle.

The third left rib was lifted 12½ months after the injury, and on digital examination, the ball was felt through the pericardium. The latter was opened and the ball was found embedded in the wall of the left ventricle, just below the auriculo-ventricular groove. Fixation stitches were introduced on either side of the ball, an incision was made over it, and it was lifted from the small cavity with a scoop. The cavity was treated with pure carbolic and obliterated by two sutures. Recovery was speedy and unimpeded. A year later the man was not capable of doing his usual work, but it is evident that this was due to the lung injury.

Indications for Operations on the Heart.

Before proceeding to formulate the indications which seem to justify surgical intervention in cases in which a wound of the heart is suspected, it may be opportune to recall the difficulties which surround the establishment of an accurate diagnosis in the gunshot injuries of war.

(1) First of all it must be remembered that in gunshot injuries the position of the external wounds may afford little or no information since they may be situated in almost any part of the trunk.

(2) Excited and tumultuous action of the heart may be due to a blow alone; while at a later date in the history of the case, irregularity and increased frequency of beat on over exertion may be due to the presence of a foreign body in the neighbourhood of the heart only, and the organ itself may be intact.

(3) The first striking fact to be gathered from the series of cases not followed by early death is that hæmorrhage may not occur in spite of a perforating wound of the heart of considerable magnitude. In other cases bleeding may be gradual or intermittent. Further, in traversing wounds the missile may have passed from the pericardium to the pleura or *vice-versa*, in which event blood issuing from the heart may collect in the pleural sac and all signs of a hæmo-pericardium be absent, as in Case 32. Lastly, when blood does collect in the pericardial sac, the strength and resistance of the walls cause the effusion to accumulate in the deeper part of the cavity and the præcordial dullness may not be materially increased in extent.

(4) The auscultation signs are identical whether the blood emanates from the heart or the pericardium. This is not a serious matter, since the treatment of a hæmo-pericardium causing pressure on the heart and impeding its action would be similar in either case. The more troublesome source of confusion lies in the fact that certain abnormal sounds such as pericardial friction may be simulated by the presence of mediastinal emphysema, and that such a typical phenomenon as the churning or mill sound has been noted when no hæmo-pericardium was present; hence, in deciding, very expert investigation is required.

The tapping sound of Rees and Hughes, and the pericardial knock of Maynard Smith seem to have been evidence of neighbouring injury rather than of a real cardiac lesion, yet in one of the cases a foreign body was actually impacted in the interventricular septum.

(5) Investigation with the fluorescent screen, or better an X-ray photograph, may furnish evidence of much value, such as the presence of injury to the skeleton in the cardiac region, the outline of the heart and pericardium, obscuration of the movements of the heart in the presence of effused blood, the extent of a pericardial effusion, the presence or absence of blood in the left pleural sac, the presence of gas or air in the pericardial sac, or the presence or absence of a missile.

The detection of a foreign body and the determination of its position and depth from the surface of the body are comparatively simple, but the further information as to whether it is located in the mediastinum, the pericardium, the wall of the heart, one of the cavities of the heart or even in the lung is not always easy to obtain.

The fact that the missile is within the heart, or lodged in the wall may often be positively determined. The foreign body will shift with the varying position of the heart in changes of posture of the patient, and it will also move in consonance with the movements of the heart and of respiration. When, however, the missile lies within the confines of the pericardium or even in the lung, the nature of the movements does not afford such positive information, since those of the heart may be communicated to it in addition to those of respiration.

Experience gathered from the cases related above seems to justify the laying down of the following indications for operations upon the heart and pericardium :—

(1) The presence of pericarditis in connection with a wound, for purposes of drainage, possible removal of a missile, or the repair of a non-penetrating wound of the heart.

(2) Hæmo-pericardium accompanied by signs of impeded cardiac action.

(3) The presence of a foreign body impacted in the pericardial sac, in the wall of the heart, or lodged within its cavity.

The operations may be immediate or remote.

The question of immediate operation may be affected by the nature of the missile and by the site at which it is lodged.

Speaking generally no urgency exists when the missile is a clean undeformed rifle bullet situated either within the confines of the pericardium, or in the wall of the heart. In these circumstances there is little fear of infection and in the absence of any urgent symptoms a convenient time may be chosen for the removal of the foreign body.

A fragment of shell, with its power to infect, demands early removal in view of the frequency and fatality of this consequence.

In cases where there is impaction of an infected missile in the pericardial sac, or in the heart wall, a primary operation is called for in view of the observation of the frequency with which death follows from pericarditis.

When the missile lies within the cavity of the heart its position in one of the chambers of the right and left side respectively should affect the question of early removal.

The missile will probably remain within the heart only as long as quietude and the supine position are maintained. When the erect posture and activity are resumed it will be passed on into the peripheral circulation.

From the right ventricle an embolus of this nature will obstruct one of the larger pulmonary vessels, where it is not easy of removal, and will be a source of great danger. Hence a prompt operation is indicated.

In the case of the left ventricle, experience has shown that the embolus may pass into the subclavian, the axillary, or the iliac vessels from any of which positions it may be readily removed with safety. It is therefore open to question, whether it is not preferable to give the foreign body the chance of reaching one of these, or in the case of small bodies a still more favourable position, rather than subject the patient to the risk of cardiotomy. The former course is probably the better as the less hazardous to the patient and as being devoid of any serious risk.

(4) The advisability of remote operations is to be determined by the nature and severity of the symptoms. These have usually been rapidity and irregularity of the cardiac action on exertion, dyspnœa, retro-sternal pain, deep pain in the chest and inability to lie in certain positions. As a rule none of these symptoms is severe, but it must be borne in mind that impacted foreign bodies have been the cause of serious recurrent inflammation (Case 8), and have also been found lying within a cavity containing pus (Case 11).

Prognosis of Operations on the Heart.

Published results have fully confirmed the justification and the hopefulness of active surgical intervention in cases of wounds of the heart, but the large series of collected instances perhaps shows results in a more favourable light than is actually correct. This for two reasons, first that, as is commonly the case, favourable results have been more freely recorded than failures, and secondly because the recorded cases differ materially in severity of the lesions dealt with. Sir Charles Ballance in his Bradshaw lecture has traced the history of this branch of surgery, and collated 152 operations with a mortality of no more than 31·57 per cent. Of these operations 63 occurred in military practice, with 16 fatalities or 26·03 per cent.

Professor Tuffier deals with 305 operations with 149 deaths, and 5 cases in which the final result could not be ascertained, a mortality of 49·66 per cent.

In any future series of statistics it would seem better to draw a sharp distinction between the cases in which the cavity of the heart is opened, and those in which this is not the case, since the two types of injury stand on a quite different basis both from the point of view of technical difficulty, and from that of risk to the patient.

The six operations recorded above, performed by surgeons in the British Army, furnish sufficiently good results.

Three of the patients died (Cases 34, 36 and 37); in two of these the ventricle was freely opened, while in the third

infective pericarditis was the indication for intervention. Of the three successful cases, Case 35 was of a valvular wound of the right auricle; Case 38 was of a furrow wound of the ventricle, in which a perforation, if present, was small; the third, Case 39, was a remote operation for the removal of a foreign body from the wall of the heart.

It is obvious that although the general mortality is 50 per cent. the successful cases belong to quite a different category from that to which the unsuccessful ones should be assigned.

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CHAPTER XVII.

WOUNDS OF THE ABDOMINAL VISCERA.

FOR many years it had been held that the operative treatment of abdominal wounds was not to be advised under war conditions. This was partly due to want of success, and partly to the fact that many military surgeons were opposed to extensive operating anywhere near the firing line. As abdominal surgery to be successful must be done at once, it is obvious that it could not be undertaken with success where all operations had to be postponed to a late period. Although the expectant treatment was the orthodox one when the South African War broke out, many surgeons hoped then to prove that it was wrong. Colonel W. F. Stevenson, the Professor of Military Surgery at the Army Medical College and Consulting Surgeon to the Force at the time, even issued an appeal for the trial of operation. The result was, however, only to confirm former opinion, though this opinion was now held on two somewhat different grounds. One school held that the expectant treatment was, in itself, the right procedure, the other that it was the best that could be done in war.

The Development of Abdominal Surgery in the War.

In the retreat from Mons adequate provision for operating near the front was an impossibility, and all that could be done for some time in the front area was to transfer the wounded to the base with the least possible discomfort to them. When the line became fixed the conditions were very different, and there was a possibility of operating under good conditions. It was no longer a question of whether a man could be operated upon, but whether he should be operated upon. Still, however, the old belief in the efficacy of the expectant treatment obtained.

With the idea of avoiding the disturbance of movement, a man wounded in the abdomen was sometimes retained in the regimental aid-post; often he was kept at a main dressing station, but usually he was transferred to the casualty clearing station and there treated. The usual mode of procedure was to put the man in the Fowler position, to improve the general condition by rest and warmth, to withhold food and water

for three days, and to administer morphia. Thirst, which was a distressing symptom of this treatment, was combated to a certain degree by rectal salines and mouth-washes.

A great tribute must be paid to the care and attention which the medical officers lavished on the cases. Certain officers were told off day and night to attend to these patients, and everything that could be done to alleviate their suffering, to make them as comfortable as possible and to cheer them up, was done. If anything could have got these men well the attention that they received would have done so. Those who conducted the treatment were firmly convinced of its efficacy, and this belief was strengthened by the behaviour of the patient. Many patients, at first gravely ill, went through a period of improvement which often was very striking. It was, in a way, unfortunate, but there is no doubt that improvement did take place, and so well were many of the wounded that they were evacuated to the base and arrived there sometimes in good condition and sometimes gravely ill.

If evacuation of these cases had not been necessary and it had been possible to keep them at the casualty clearing stations, the expectant treatment would not have survived as long as it did, for medical officers would have seen such cases become worse and worse, and in the end die. The expectant treatment was also a very trying time for the wounded man. The knowledge that nothing could be done for him by operation, and that the only thing was to wait events, had a very depressing effect on the soldier. Although rest treatment was the rule in the first days of the war, some attempts at operation were made. H. S. Souttar, working with the Belgians, commenced early operation in September 1914. Captain Owen Richards was the first to publish results of operative treatment in the British Army. His first operation was performed on 28th January, 1915, and the first successful case, that of a resection of 2½ ft. of the small intestine, was operated upon on 18th March, 1915, thirty-six hours after receipt of the injury. A few other British surgeons had tried what could be done by operation both in the field ambulances and in the casualty clearing stations, but the results were undeniably bad, so bad that most people had abandoned the attempt. The reason for this was, no doubt, the late arrival of the cases at a place where an operation could be performed. By June 1915 a series of operations and post-mortem examinations showed that the injuries were of such a nature that recovery was not to be expected without surgical aid except in a few instances.

It was also found that hæmorrhage was a frequent cause of early death, and that bullets produced very extensive injuries.

It has always been granted that hæmorrhage was the chief cause of early death, but the advocates of expectant treatment seem to have focussed their attention more on the danger of peritoneal infection and the possibility of its localization or disappearance than on the possibility of spontaneous arrest of hæmorrhage. The discovery that bullets produced extensive gut injuries was also of great importance, as much stress had been laid on the smallness of the lesions produced by the modern small-bore bullet in the South African War; in fact, the hope of spontaneous recovery from gut lesions was based on the assumption that such projectiles were comparatively innocuous. This idea was constantly put forward in the early period of the war.

The re-establishment of the fact that hæmorrhage was the chief cause of early death was of great importance, as it showed that only by rapid evacuation could such a condition be combated. In June 1915, Surgeon-General W. G. Macpherson, when D.M.S. of the First Army, directed some of the field ambulances to send the abdominal wounds with all possible celerity to the nearest casualty clearing station. The results obtained by this small experiment were encouraging, and in the first week of August 1915, an order was given which made the rapid evacuation of abdominal wounds the official method in a certain sector of the line. This was followed by rapid improvement in the results obtained, and the operative treatment soon became adopted throughout the armies.

The quick evacuation of all abdominal cases to the casualty clearing stations put a great deal of responsibility on the field ambulance officers. It was no light task to decide what cases could stand evacuation. Many patients, of course, were better for rest, food and warmth; but in the case of abdominal wounds it must be remembered that hæmorrhage was the chief cause of early death, and that the only hope for their salvation lay in the arrest of the hæmorrhage by surgical means. It was therefore obvious that it was worth while taking risks in cases of abdominal wounds which it would not have been right to take in other cases. There was also the danger of death from peritoneal infection, but experience showed that the need for celerity on this account was as nothing compared with that necessary on account of hæmorrhage.

Special advanced hospitals for abdominal and thoracic wounds were opened for the Battle of Loos. This practice was continued throughout the war and under the name of advanced operating centres they were generally available for all severe wounds. Sometimes a casualty clearing station was set apart, sometimes a field ambulance reinforced by one or more surgical teams was used. There was some difference of opinion as to their advisability in times of heavy fighting, since segregation of cases in the forward areas tended to complicate evacuation. In quiet times there is no doubt that they were invaluable.

In the earlier period of the war there was some difficulty in arriving at an accurate figure showing the relative frequency of abdominal wounds. With the establishment of the operative treatment, however, and the keeping of accurate records the errors diminished. It is now possible to state that the number of abdominal wounds that reach an operating centre is not likely to exceed 2 per cent. of the total wounded received, provided that no segregation of such cases is practised.

Effects of Projectiles.

Many different kinds of rifle bullets were used in the war. As is well known, the standard British, French and German bullets were pointed. The British and German were composite projectiles liable to break up into mantle and core. The French bullet was much longer than either of the above, and was made of solid copper alloy. Although not liable to break up, it was liable to very great distortion. All the modern pointed bullets are more unstable than the bullets of the South African War. The instability is said to be most marked at the beginning and the end of the flight. During the war when fighting took place amongst houses, there were many opportunities for the bullet to be deformed and deflected. Again, the velocity and stability of a bullet were largely affected by passing through sandbags or a parapet, which, as matter of fact, had to be something like 4 ft. thick to be bullet-proof. There is plenty of evidence that, whether from inherent instability or from hitting some object, the bullet did spin, and in several cases a bruised impress was seen on the skin which could only have been made by a sidelong impact. Again, in those cases where two legs were wounded by the same bullet the first leg was perforated by a small standard track, and the opposite leg suffered a large gaping wound, the obvious explanation being that the bullet in passing through the first limb was made to spin, and so caused a more extensive wound on the

opposite member. A good deal has been heard about the explosive effect of the modern pointed bullet; and although it may be said that it does cause worse wounds than the ogival-headed projectile, it is by no means certain that its so-called explosive effect was anything but a rare occurrence. This opinion is strengthened by the study of accidental wounds, of which there was a great number. Men were shot at all sorts of close ranges up to actual contact, and yet, unless a hard bone was touched, it was not usual to get the explosive type of wound.

Shell fragments were of all sizes, but the fragments which were the cause of the abdominal wounds that the surgeon was called upon to treat were generally not more than $1\frac{1}{2}$ ins. in the greatest diameter, usually much smaller. Some importance was attached to the nature of the shell by which the man was wounded.

High-explosive shells might burst in the air, on contact with the ground, or after they had impacted themselves deeply in the earth. The velocity of the fragments into which the shell was blown depended both on the "remaining velocity" and on the disruptive charge, and the fragments flew out mostly in a forward and lateral direction. The shape of the fragments depended largely on the type of shell. If the shell was segmented, the pieces were more or less quadrilateral; if not segmented, the fragments were still more or less quadrilateral in shape, and had extremely sharp and ragged edges. Such shells, bursting on the ground, naturally became covered with dirt.

The knowledge of where a shell burst in relation to the patient was sometimes of importance in indicating whether the abdomen was involved. If a shell burst above a man who was wounded in the lower thorax it was likely that the fragment entered the peritoneum. Again, if a man was hit in the buttock and the shell exploded on the ground the possibility of the pelvis being involved should at once be thought of.

Shrapnel shells usually burst in the air with a time fuze. They were all sizes, and the metal balls with which they were filled also varied in size. The penetrating power of such balls was due to the remaining velocity of the shell. The direction of the shrapnel balls was, as a rule, downwards.

Shell caps came from both types of shell and formed some of the largest fragments that the surgeon met with. They often caused contusions without perforation.

In the early part of the war bombs were often improvised, and consisted of tin boxes filled with an explosive, scrap iron,

cobblers' nails and screws. Later they were made of iron, the surface of which was often marked with grooves, so that on explosion they broke up into quadrilateral fragments. Sometimes the force of the explosive would cause a bomb to burst into smaller fragments, often no bigger than a big match-head. Although small, these fragments had, apparently from their high velocity, a very great penetrating power in the immediate neighbourhood of the explosion, though this was rapidly lost as the distance increased.

Bombs from trench mortars were of various shapes but consisted essentially of a very large high-explosive charge with a comparatively thin containing envelope; they therefore very often burst into large ragged as well as minute fragments. They were generally timed to burst either on or in the ground.

Bayonet wounds were very seldom met with, being usually fatal on the field. Mention may be made of two cases. In the first, the bayonet penetrated the man's back and came out by his umbilicus; no viscus was injured, and the man succumbed to hæmorrhage. The second was the case of a man who was late in answering a challenge, and was bayoneted by the sentry; the bayonet entered the left hypochondrium, wounded the greater curvature of the stomach, and entered the back wall of the abdomen; though promptly operated on, he died, not of his stomach wound, but of retroperitoneal sepsis.

Table I gives some idea of the relative frequency of the different projectiles met with in abdominal wounds in a series of 834 cases; it also shows the number retained in the body. This table must be taken as only approximately correct. In the first place, it is often impossible for a man to tell what hit him; in the second place, one cannot always be sure, from a study of the entrance and exit wounds, what was the nature of the projectile; and again many did not differentiate between high-explosive shell and shrapnel, the soldier generally including most shells which were not of a large calibre under the name of shrapnel. As a matter of fact, there is very little difference in the nature of the fragments in high-explosive shells, bombs, rifle grenades, or trench mortars, if the larger fragments are excluded.

Bullets and high-explosive shell furnished the larger proportion of abdominal wounds. More bullets passed through the body than other projectiles; the reason for this is obvious. The causes for retention are not so obvious, and bullets fired at a comparatively short distance have been

known to remain within the body. In other cases the bullet might have passed through earth, and so have had its velocity diminished. Ricochets accounted for a certain number.

Shells showed a high proportion of retention, which was obviously due to the shape of the fragments.

In the case of bombs and grenades the retained fragments were strikingly in excess of those passed out.

TABLE I.

Relative Frequency of Different Projectiles met with in Abdominal Wounds and of those retained. Total number of cases, 834.

	Bullet.	Shell Fragment.	Shrapnel.	Bomb or Grenade.
Out	203	30	15	6
Retained	131	254	67	128
Total	334	284	82	134

With regard to the relative mortality of the different projectiles, the following table shows that, in a series of 629 cases, bullets were but little less dangerous than shells, and that bombs and grenades were the least noxious.

TABLE II.

Relative Mortality in 629 *Cases.*

	Bullet.	Shell Fragment.	Shrapnel.	Bomb or Grenade.
To Base	91	105	15	60
Died	106	154	40	58
Total	197	259	55	118

Regional Incidence of Abdominal Wounds.

The following charts were made by plotting the entrance wounds on the front and back of the body respectively. The wounds of the back form a substantial proportion of the whole. There is a tendency for the wounds to collect towards

the sides, especially on the back of the body. The comparative absence of mid-line wounds is also seen in Fig. 2, which represents the wounds in cases too bad for operation when they reached the casualty clearing station. This distribution is brought about by the presence in the mid-line of the spine and the great vessels. Men shot in these situations died on the field of battle. The collection of

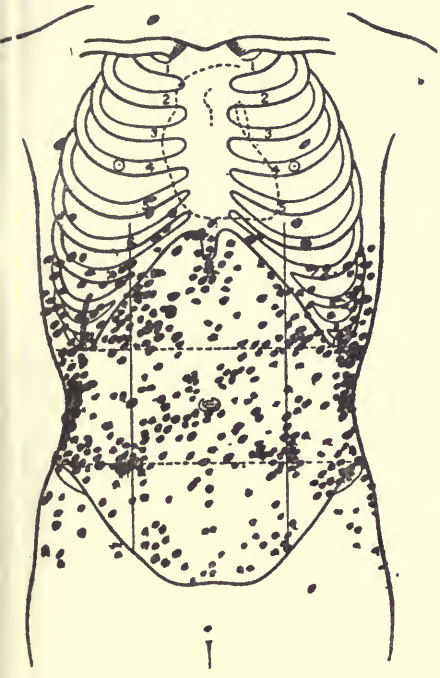


Fig. 1.
Regional incidence of wounds. Front view.
429 wounds. Mortality 53 per cent.

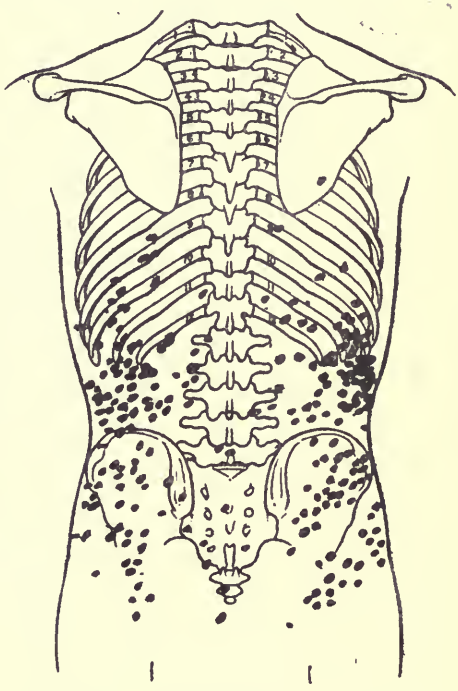


Fig. 2.
Regional incidence of wounds. Back view.
222 wounds. Mortality 60 per cent.

wounds towards the sides of the body might possibly also be caused by the fact that a man's front and back were more or less protected in the trench, while the sides of the body were open to enfilade fire.

Cases too serious for Operation.—The chart (Fig. 3) was obtained by plotting the entrance wounds and the track of the bullet, when known, in those cases which arrived at the casualty clearing station in such a condition as to preclude any operative procedure; they all died. It is rather striking to notice how

the chart becomes blackened in a fan-shaped area, the apex of which is the left hypochondrium. There is a comparative absence of mid-line wounds and of hypogastric wounds. This must not be taken as meaning that hypogastric wounds were not dangerous, but only that they did not cause such injuries as to render operation useless. The side-to-side wound would appear to have been the most dangerous among wounds that reached an operating unit. This seriousness was noticed in the South African campaign.

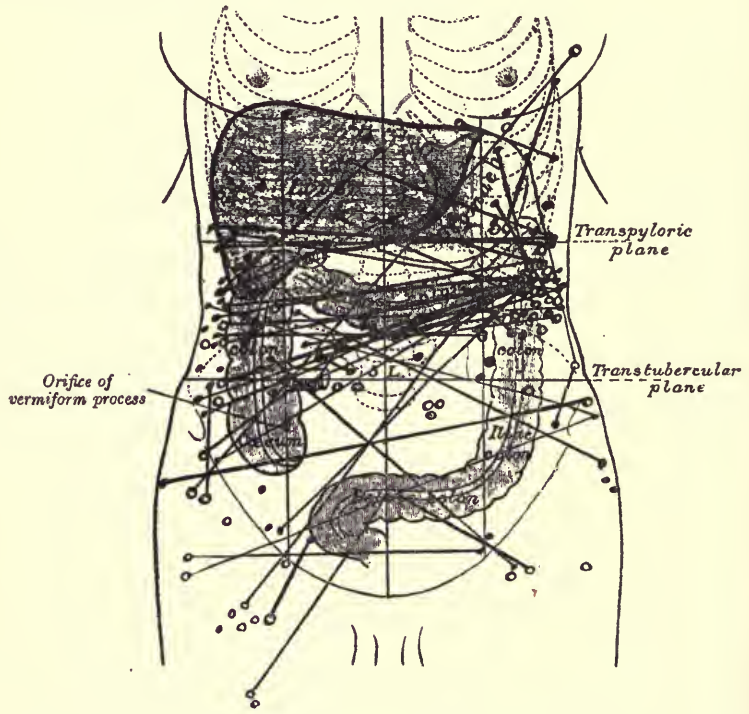


Fig. 3.—Chart of cases too seriously wounded to be submitted to operation, all being fatal. A black dot represents an anterior wound, a circle a posterior wound; the track of the projectile is shown by a line.

In the chart (Fig. 2) there are many buttock wounds. From experience gained in operating on such cases, lesions of the pelvic vessels must be regarded as a fairly frequent cause of death.

The mortality that accompanied abdomino-thoracic injuries is possibly explained in part by the fact that such wounds involved this dangerous hypochondriac area.

In sixty-eight cases a post-mortem examination was performed; Table III shows the injuries, and Table IV the number of times individual organs were hit. In nearly every case there was much blood in the abdomen, and in thirteen cases the note is made that death was due to hæmorrhage.

In one case retroperitoneal sepsis was noted as the cause of death, and in only three instances was death due to peritonitis. The number of times the small gut was injured is the salient feature in the series. Wounds of the solid organs were responsible for death in twelve instances.

TABLE III.

Showing Injuries in Moribund Cases.

Stomach and kidney	2
Stomach and colon	1
Stomach and liver	1
Stomach, liver, spleen and pancreas	1
Small gut	27
Small gut and colon	4
Small gut and rectum	2
Small gut and embolism from wounded carotid	1
Colon	5
Colon and kidney	1
Rectum	2
Liver	8
Liver and spleen	2
Liver and kidney	1
Spleen and kidney	1
Bladder	3
Paraplegia and acute dilatation of stomach	1
Prolapse of stomach, small gut and colon	1
Prolapse of stomach, colon and spleen	1
Prolapse of small gut	1
Prolapse of spleen and splenic flexure	1
Wound of internal iliac vein	1
	68

TABLE IV.

Showing the Number of Times Individual Organs were Wounded.

Stomach	5
Small gut	34
Colon	10
Spleen	4
Liver	13
Kidney	5
Rectum	4
Bladder	3
Pancreas	1

Recovery without Operation.—Fig. 4 was obtained by plotting the entrance wound and the track of the missile, when known, in cases that recovered without operation. Most of these

wounds lie within the liver area. The chart also shows wounds in other parts of the abdomen, and recovery therefrom, as will be seen later, was most probably due to the fact that the hollow viscera had escaped although the abdomen had been penetrated.

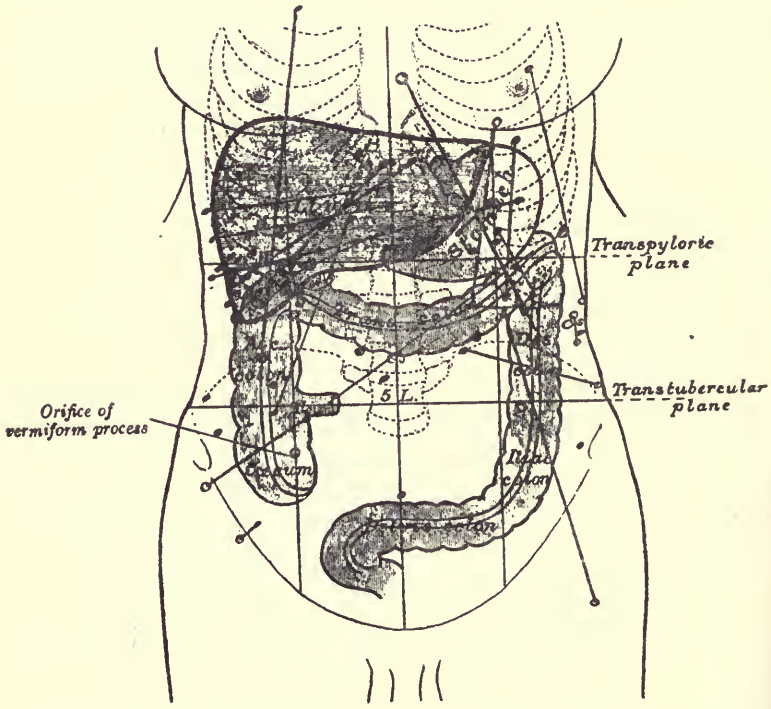


Fig. 4.—Chart of cases that recovered without operation. Dots, circles and lines have the same significance as in Fig. 3.

Uninjured Viscera in Penetrating Wounds.—It has always been a much-debated point as to whether a projectile could traverse the peritoneal cavity without wounding the hollow viscera. Makins, from his experience in South Africa, held that it was possible. Others denied the possibility. There has never been any doubt that the liver and kidneys could be damaged without involving other organs. The point that required settling was the escape of the stomach in the upper part and the small intestine and colon in the lower. Those who believed in treating abdominal wounds by rest and starvation pointed to cures by this means of patients in whose

cases it appeared, by a study of the track of the bullet, that a hollow viscus must have been perforated. Makins held that there was a possibility of recovery in cases of colon injury, but that small-intestine lesions were always fatal. Until cœliotomy became the routine treatment of abdominal wounds, a proof that such escape was possible was almost wanting. The classical case of Cheatle's was often quoted as a proof, but there were people who were not convinced by it.

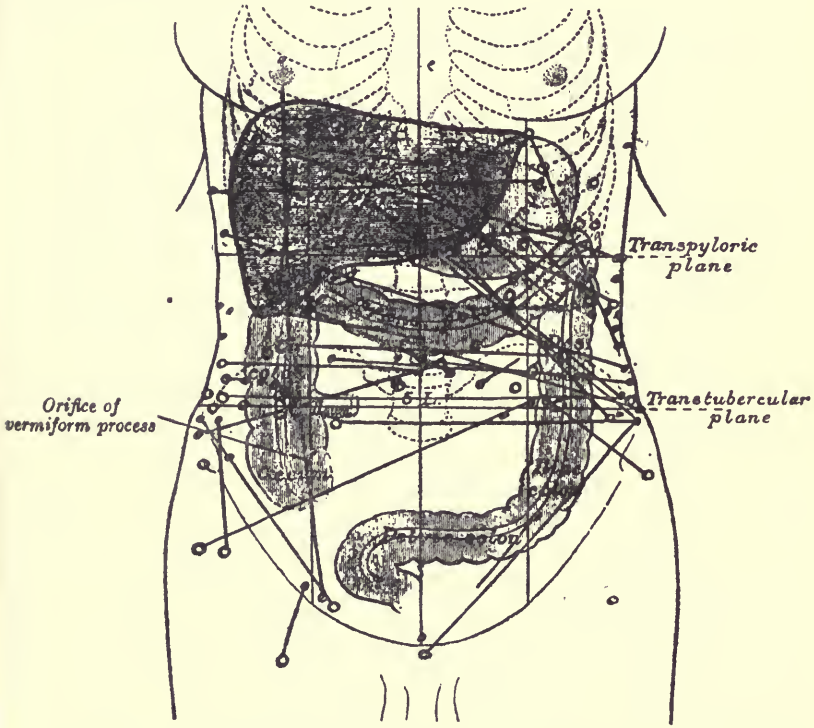


Fig. 5.—Chart of cases in which cœliotomy was performed and no hollow viscus found injured. Dots, circles and lines as in Fig. 3.

Fig. 5 shows a chart of cases in which the abdomen was opened and explored, and no hollow viscus found injured. The abdominal cavity was usually full of blood. This blood came from two sources, namely, from the vessels of the omentum, mesentery, or abdominal wall, usually the deep epigastric, and from cracks in the peritoneum raised by a retroperitoneal effusion of blood; here little beyond clearing the abdomen could be done, for experience has shown that such collections of blood are best left alone.

In many cases there were bruising and tearing of the peritoneal and muscular walls of the stomach or intestine. These tears and bruises explain the cases where a fæcal fistula or an intra-peritoneal abscess had appeared some time after the receipt of the wound.

Spontaneous Recovery after Perforation of Hollow Viscera.—It is quite true that people do recover spontaneously after wounds of the hollow viscera, but the number is very small. Those who recover may be said to be the exceptions that prove the rule. The following are instances.

Makins describes a case in which a wound of the posterior surface of the stomach was firmly sealed to the pancreas and spleen; death resulted from secondary hæmorrhage. Colonel T. R. Elliott and Captain Herbert Henry have also described cases of spontaneous healing, and Cuthbert Wallace noted a healed wound of the stomach in a patient who succumbed to other injuries. Lastly, Captain Green-Armytage actually closed the abdomen in a case where a hole in the stomach was impossible of suture, and a cure resulted.

There have been frequent instances of recovery after wounds of the vertical colons, as has been insisted on by Makins, who attributes such a favourable result to the intense local reaction produced by the contents of this portion of the bowel.

The history of the following remarkable case is given by Sir Anthony Bowlby and Captain Bell. A soldier was shot from side to side through the body at the battle of Loos. He was not operated on, and recovered. There was nothing special about his convalescence. He was again shot in the abdomen in the battle of the Somme and was operated upon. When the abdomen was opened several perforations of the small intestine were found in the neighbourhood of a mass of adhesions. The wounded and adherent segments were excised, and the man made a good recovery. On slitting up the adherent coils an entero-enterostomy was found between two adjacent loops; in addition there were several small herniated diverticula of the mucous membrane, obviously pointing to closure of the previous penetrations. This case is of interest because the process of healing corresponded to that which Major H. Drummond showed to be the case when the intestines of rabbits were perforated and put back without suture. The herniated mucous membrane remained herniated, and gradually became covered with a layer of lymph which slowly organized and sealed the hole, the herniated mucous membrane still forming a diverticulum.

Rupture of Viscera.

By Contusion of the Abdomen.—A number of abdominal injuries were caused by horse kicks, by the falling in of dug-outs, by burial of men by shell explosions, and by blows of fragments of wood which were hurled about. They presented nothing out of the common, and the injuries seen were the same as those in civil life. Captain J. B. Haycraft had one case of a man who died after burial by a shell explosion in which the post-mortem examination showed numerous contusions of the small intestine without rupture.

Similar injuries were caused by large shell fragments, usually shell caps, and several cases of the latter injury were seen in which rupture of the intestine was accompanied by extensive contusions.

By In-driven Bone Fragments.—There were many cases of injury to the liver and spleen by the driving in of fractured ribs. The cæcum, the ascending and descending colon, and also the small gut in the pelvis were all apt to be injured by small bony spicules driven in through the peritoneum, although the projectile itself did not penetrate this membrane.

By Indirect Violence of a Passing Projectile.—Such injuries were not uncommon. Fig. 6 shows a picture of a kidney in which many cracks in the capsule were produced by a missile which did not touch the organ. The spleen was often ruptured in this manner, and sometimes the liver. In one case the diaphragm was intact, but on opening the peritoneum much blood escaped, and there was an extensive tear in the spleen. In another case the diaphragm was ruptured over a small area, the blow being a glancing one. There was a corresponding wound on the outer surface of the spleen, and from this wound there ran in all directions radiating fissures in the capsule, showing that the spleen had been burst by the indirect force exerted upon it.

By Indirect Violence.—Cases of rupture of the hollow viscera by indirect violence have been reported by Captains Owen Richards, John Fraser, J. W. Dew, and others. The first case was that of a man whose recti were divided almost completely by a bullet. The wound was explored and the posterior rectus sheath found intact. As there were no symptoms, the abdomen was not opened; the man died. At the post-mortem examination a careful search failed to show any rupture of the peritoneum. There were three holes in the small intestine which lay immediately under the wound in the abdominal

wall, showing that the gut had not moved, although more than twenty-four hours had elapsed since the receipt of the injury. Fraser's case was that of a man wounded by a piece of shell in the right iliac fossa, the cæcum being found bruised, and a small hole in the mesenteric border of the ileum. In Dew's case the projectile had cut through all the abdominal

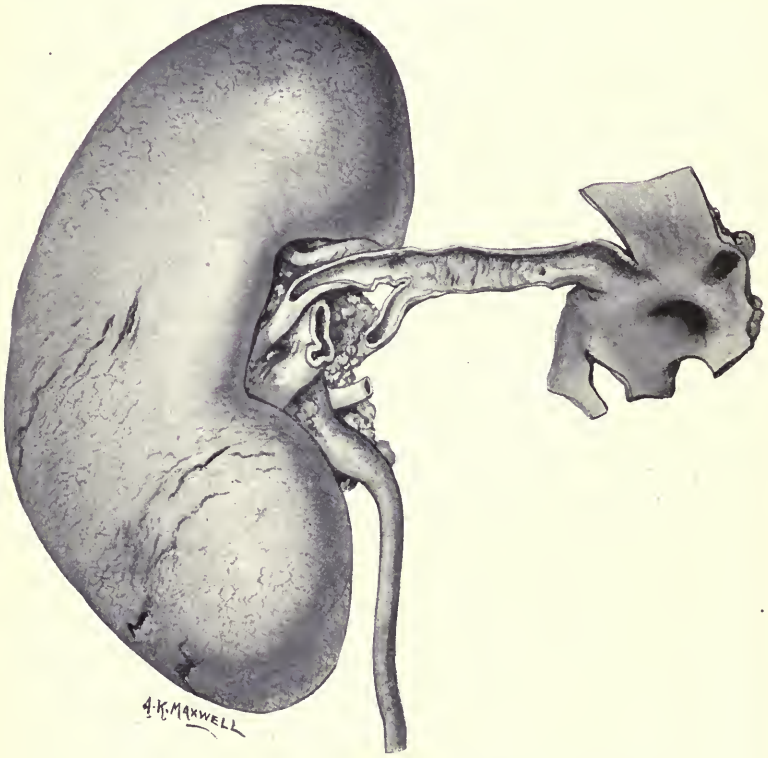


Fig. 6.—Kidney : indirect effects of bullet wound—organ fissured, concentric fissures run across the intima of the renal artery. Bullet entered left buttock, traversed sacrum and fifth lumbar vertebra, and passed out through right psoas, keeping behind the colon ; the track was quite clear of the colon and kidney.

wall except the peritoneum, through which the cæcum could be seen. As there were no symptoms the abdomen was not opened, but the man died from a ruptured ileum. Stevenson, Shaw and Mackenzie have described a rupture of liver and jejunum by a missile that did not open the abdomen.

It would seem that these ruptures may be caused in two possible ways. When an object such as the abdomen and its contents, made up of layers of varying toughness, is sharply hit, more friable layers underneath may give way, while the more resisting overlying layers remain intact. Secondly there is what may be termed the " paper-bag " theory, the viscus being ruptured by a smart blow in a similar way to that in which an inflated paper bag is burst on being hit. There is no proof that this happens, but it is rather a seductive theory. The following case of Fraser's is interesting in this connection. A bullet penetrated the abdomen just below the umbilicus ; there were no symptoms at first, but when they arose later on, cœliotomy showed a ruptured bladder. The bladder was apparently out of the direct line of the projectile.

There is another possibility which must not be lost sight of ; a man might fall to the ground, or against some object, when he was hit, and the ruptured intestine be due to the blow thus produced and not to the actual missile which was the indirect cause of the fall.

Mechanism of Wound Production after Penetration.

The multiplicity of the wounds of the small intestine has raised some doubt as to their method of production, especially in the case of bullet wounds, of which widely different types were seen. The question arises whether a bullet pursuing a straight course could cause these injuries, or whether a rotation of the bullet must be invoked or a bursting effect. If a bullet was rotating quickly on a transverse axis, it could easily produce complete division of the gut, but if it was rotating quickly enough to produce such injuries, it is hard to see how it could at the same time produce small perforations. Some support is given to the rotation theory by the retention of many bullets ; it is known that their flight is unstable at the end. If the rotation theory is correct, there ought to be some evidence of this rotation at the entrance and exit holes. As a fact, it is impossible to establish any relations between the size of the entrance and exit wounds in the skin and the amount of damage done to the intestine. As to the possibility of a bursting effect of the paper-bag theory it is impossible to make any definite statement. In a case operated on by Major Hamilton Drummond there was a rupture of the small intestine between the leaves of the mesentery which was not found until the intestine was laid open. The position of the rupture was outside the track of the bullet, as in Fraser's

case of ruptured bladder. It must be remembered, however, that the intestine is not greatly distended by either gaseous or fluid contents. It seems almost impossible to believe that anything of the nature of a hydraulic or pneumatic effect could be produced. In this connection the following case is pertinent. A soldier was shot through the abdomen, the muzzle of the rifle being in contact with the body. The entrance wound was close beside the umbilicus, and the exit

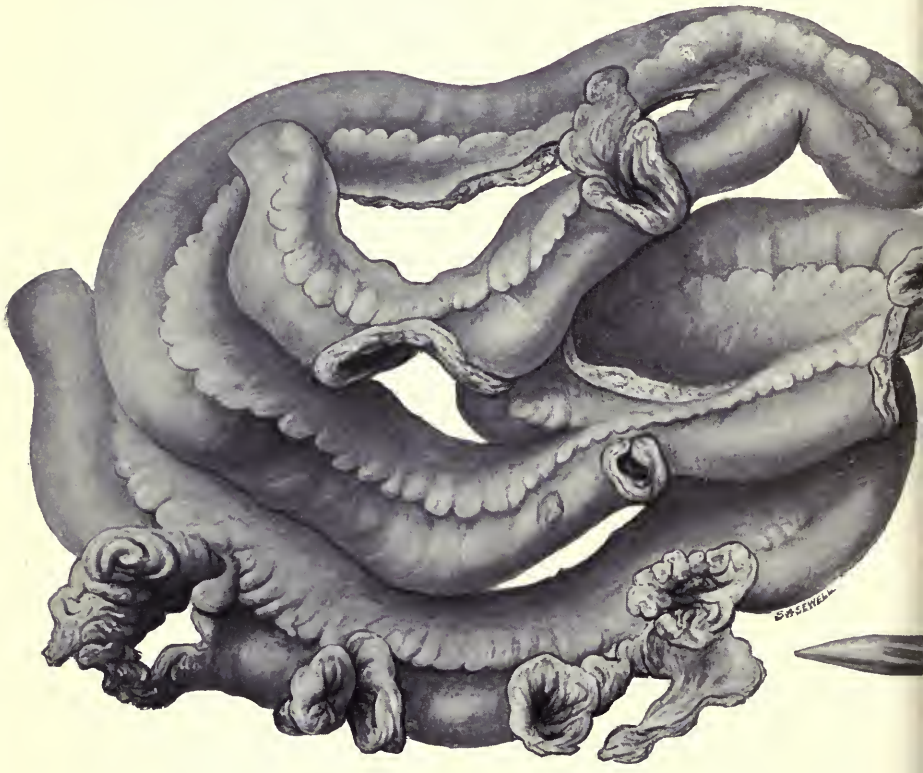


Fig. 7.—Small intestine divided in seven places by a rifle bullet. Small wound of entrance in epigastric region. Bullet lay free within abdominal cavity. Parts resected. Patient died a few hours after operation.

wound at a corresponding point behind. The bullet passed by the side of the vertebral column and made three type lesions in the jejunum. He was promptly operated on, and made a perfect recovery. If any pneumatic or hydraulic effect is to be expected, it should have been found in this

case. It is possible that these different types of wound were caused by the varying state of distension of the small gut. As is well known, lengths of the small intestine alternately distended with air and collapsed are met with. If the bullet strikes a distended portion, it will perforate it or cut a hole in it. If it strikes a portion which is collapsed, the intestine is so small that the bullet is large enough in diameter to divide both coats the whole breadth of the bowel.

Some support is given to this assumption by the behaviour of the large gut. Perforations are here much more common than large tears or complete division. When complete division does occur it is in the portions of the gut that are often found small and collapsed, namely, the transverse and descending and pelvic colons. The ascending colon and hepatic flexure nearly always show perforations rather than complete division.

Frequency of Wounds in the Different Viscera.

The following table gives some idea of the relative frequency with which different viscera in the abdomen were wounded in a series of 965 cases.*

TABLE V.

Relative Frequency with which Different Abdominal Viscera were Wounded in a series of 965 *Cases.*

Viscus.	No. of times wounded.	Viscus.	No. of times wounded.
Small gut	363	Spleen	54
Colon	252	Bladder	45
Liver	163	Rectum	21
Stomach	82	Pancreas	5
Kidney	74	Ureter	3

* All the statistics, except where otherwise mentioned, in the chapters on abdominal wounds are derived from cases admitted to operating centres of the First Army in France over a period of 18 months (1st July 1915 to 31st December 1916). The 965 cases, to which special reference is made in the tables, are cases which were operated upon either by Sir Cuthbert Wallace or by the surgical specialists of the First Army.

Influence of Contents of the Alimentary Canal.

Stomach.—The amount of food in the stomach was dependent on the time that had passed between the last meal and the time of wounding. The escape of contents depended on this, and on the size and situation of the wound. If the wound was small and near the lesser curvature or the cardiac end, there would be little found in the abdomen; if, on the other hand, the wound was large and near the greater curvature, extravasation might be very considerable. It was only in connection with the stomach that free gas was seen to escape from the wound or to be present in the abdomen.

The Small Intestine.—The small intestine was usually empty, and it is hard to fix any definite relation between the amount of its contents and the time of the last meal. It is in a very favourable condition from a surgical point of view, even more so, perhaps, than after the elaborate preparation which has been till recently the rule in civil operative practice. The collapse of the gut was not due to escape of gas, for free gas was not found in any quantity in the abdomen.

The usual absence of any large amount of intestinal contents seems to have been due to a more rapid passage of food along the tube than is usually considered normal, or else to a very complete digestion. Otherwise, considering the number of cases treated at various intervals after meals, the presence of contents should have been more frequent. It was the absence of contents, more than anything else, that accounted for the little extravasation. Should the intestine be loaded, there was a large escape.

In one case under Major H. Drummond it was possible to get the exact time of the last meal. A man had a dinner of beef and beans at 1 p.m.; he was hit at 6 p.m., and operated on at 10 p.m. All evidence goes to show that digestion and vermicular movements cease after a wound, so that it may be assumed that the state of the intestine at 10 p.m. was the same as at 6 p.m. The operation showed that the man was wounded $3\frac{1}{2}$ ft. from the cæcum, and here the bowel contained much fluid and solid matter, including beans, which were extravasated to a large extent.

Another interesting observation was made by Captain John Fraser. A detachment of soldiers was shelled in billets just after the midday meal, at which large quantities of tea were consumed. Several were wounded in the abdomen. The amount of fluid in the abdomen in some cases of wounded small gut was remarkable and in contrast to the usual condition.

It looked as if the fluid contents had passed rapidly into the small intestine. The stomachs themselves—to judge by one case, at all events—were still full of food. It is interesting to note that according to Major C. H. Barber, I.M.S., extravasation is apparently more common in vegetarians than in meat-eaters.

The Large Intestine.—This was often loaded and in this respect presented a great contrast to the small intestine. This fact, no doubt, was due to the sedentary life in the trenches. The loaded state of the bowel might have some relation to the infectivity of the contents. On the other hand, a constipated condition tended to limit the escape of the contents.

Influence of the Nerve Muscular Mechanism of the Alimentary Canal.

A sharp distinction must be drawn between the appearances seen before and after sepsis has produced its effects on the intestine. The following description refers to conditions before sepsis.

The Stomach.—This was often normal both as regards its size and the thickness of its walls. On the other hand, it was by no means rare to find it dilated. This dilatation was, as a rule, of moderate dimensions, but might be of considerable extent, and occasionally a condition of acute dilatation was present. This last condition was seen both in peritoneal and retroperitoneal wounds and with and without spinal injury. Apart from actual dilatation seen in the course of operation, many cases after operation presented the clinical symptoms of the condition, which was relieved as a rule by stomach lavage, but sometimes ended fatally.

An experiment performed by Major H. Drummond and Sir Cuthbert Wallace may be of interest in this connection. A dog was given a weighed meal containing bismuth. A skiagram showed that the stomach emptied itself in six hours. The experiment was repeated, with the addition that the animal was anæsthetized for half an hour. There was no delay in the emptying of the organ. Another experiment was performed similar to the last, but in this instance a resection and suture of intestine was performed. The stomach had not begun to empty itself in six hours.

The following case shows that the loss of motile powers was not altogether dependent on a penetrating wound. An officer had his dinner at 7 p.m. Immediately afterwards he took his platoon into the trenches. On the way up some

obstruction occurred in the communication trench, and the officer got out of the trench to put matters right. His femur was shattered by a bullet at 10 p.m. The next morning at 11 a.m., having had no food in the interval, he was given an anæsthetic in order that the wound might be treated in the ordinary way. He vomited his dinner practically unaffected by digestion.

The Small Intestine.—This presented alternate lengths of moderate distension and collapse, and on the whole the calibre of the tube was on the small side. Sometimes this condition was exaggerated and the appearance of the abdominal contents when first seen on opening the abdomen was comparable, as Fraser has said, to that of a formalin injected body. Very occasionally a wounded segment of the gut presented a local dilatation at the lesion.* Sometimes the upper jejunum shared dilatation of the stomach.

The intestines remained motionless a considerable time after injury. This was shown by the fact that when the missile had taken a comparatively superficial course, and wounded the gut as it lay against the anterior belly wall, the injured part was still found in the same place after a considerable interval. The same occurrence was noted in those cases where the gut had been ruptured without abdominal penetration, and death had ensued. Cuthbert Wallace saw the wounded gut still in the place in which it was hit after thirty-six hours. The adhesions that quickly formed after wounding no doubt anchored it in place after motility had reappeared. Sir William Watson Cheyne described a similar case in the South African War, where the gut remained in position after three days.

Drummond and Fraser raised the interesting point as to whether an extensive injury of the small intestine might not, to a certain degree, assist in its own cure by causing a more profound paralysis than does a more trivial injury.

It is at present impossible to say definitely how long on the average the gut remained paralysed; the only other observation bearing on this subject was that peristalsis had been seen in the jejunum eleven hours after injury.

It is possible that a persistence of the traumatic paralysis of the gut was the source of trouble after a resection, and two cases apparently of this nature were reported by Richards and Fraser.

Some experiments performed in France seemed to show that in animals, after a resection, the upper segment of the intestine remained paralyzed after the lower one had regained its power,

* See Fig. 2, Chapter XVIII.

and that the last part of all to become normal was that in the immediate neighbourhood of the resection. It is possible to start a peristaltic wave in the lower segment some time before it can be originated in the upper; and even when a contraction can be brought about in the upper segment, it fails to pass downwards, remaining as a stationary constriction of the gut.

Effect of Time of Operation on Results.

Table VI was compiled from a series of 591 cases by dividing the time between the receipt of the wound and the performance of the operation into two-hourly periods, and noting whether cases were sent to the base or succumbed to their injuries. It mainly shows two things: (1) it gives some idea of the time in which cases are got out of the trenches and submitted to operation; and (2) it shows the effect on the mortality of the time which has elapsed between the receipt of the injury and the performance of the operation. It will be seen that most cases arrived between six and ten hours after the receipt of the injury. Up to six hours the chances were in favour of the patient; after this period they were always against him. The limit in successful cases was forty-eight hours for a resection of the small intestine and thirty-six hours for a suture of the colon and for a suture of the stomach.

TABLE VI.

Result.	Time of operation after injury in hours.											
	2	4	6	8	10	12	14	16	18	20	22	24 and over.
Evacuated to Base ..	3	30	75	55	34	19	7	4	11	4	0	27
Died ..	2	30	53	59	41	23	10	12	15	11	4	52
Total ..	5	60	128	114	75	42	17	16	26	15	4	79

Relation between the Amount of Injury and the Amount of Collapse.

Something may be learnt from studying a man's sensations when hit. They vary in a remarkable degree. As examples of this the following may be quoted. A man had his abdomen ripped open by a bullet just as the troops were compelled to evacuate a trench. He was bandaged up with a field dressing and insisted on walking to a trench in the rear, where he lay on the fire step till quiet had been restored. He was then

evacuated and made a good recovery. A party of men were marching along a road just outside an advanced operating centre when an aerial bomb exploded in their midst. Twenty-two were brought in dead within a few minutes. Twelve had abdominal wounds, and of these the intestines were exposed in ten instances. Sometimes a man did not know that his intestine was prolapsed. A soldier was hit just above the pubes; he experienced very little inconvenience; when the first dressing was applied some of the small gut lay in the abdominal wall. He was taken to hospital, where he arrived in good condition and free from pain. Six to seven feet of the small gut then lay outside the abdomen perforated in several places. He made a good recovery.

Sometimes a man hit in the abdomen believed that the injury was in the thigh or leg, a nerve having been injured, giving rise to reflected pain.

One man, who subsequently died of peritonitis from a perforated ileum, when seen six hours after the injury was in good condition, free from pain, cheerful, and smoking a cigarette.

As a rule a man hit in the abdomen did, however, suffer pain, often intense, dating from the moment of infliction. The suddenness of the pain recalled that experienced in gastric perforation; it might be accompanied by collapse, transient or persistent.

Small missiles might cause either a sharp stab or the feeling that a tremendous blow had been administered. This sensation was also experienced in wounds of other parts of the body, and it is interesting to remember that it is also felt by those who rupture muscles while playing games.

The actual comparison of the amount of injury and the amount of disturbance is very difficult to determine. There were many obstacles in the way of accurately gauging the bearing that trauma had on collapse. Regimental medical officers who saw the cases early could form no judgment, beyond gross lesions, as to the amount of intraperitoneal damage, and by the time the cases reached a medical unit it was impossible to exclude other factors in most cases.

Exposure or prolapse of the upper hollow viscera usually caused collapse, and so did avulsion of large portions of the abdominal wall.

Multiple lesions of hollow viscera produced a high mortality, but multiple lesions meant a long operation and were usually accompanied by much bleeding. It seemed that multiple

lesions did not as a rule produce collapse provided hæmorrhage and sepsis were absent. Recovery has followed as many as twenty lesions.

Shattering wounds of spleen and kidney cannot be said to have been alarming injuries in themselves. Extensive wounds of the liver, on the other hand, were alarming. Where both kidneys were involved death followed, but this could not be attributed to collapse.

Finally, three cases may be quoted to show that abdominal injuries might in some cases completely incapacitate a man and in others did not at once prevent him from continuing his work.

An ambulance driver was hit in the abdomen by a shell fragment. He experienced severe pain, became collapsed, broke out into a profuse sweat and vomited. He continued collapsed until the operation, which revealed perforative lesions in the small gut and a considerable amount of blood in the abdomen. He recovered.

A bearer in the Royal Army Medical Corps wounded in the intestine, as a subsequent operation proved, was brought to an advanced dressing station on a stretcher. As there were many wounded to be attended to, he got up and assisted in the work.

An airman was hit by a shell fragment far behind the German lines. He brought his machine safely back and made a good landing. He reached a hospital in good condition. Two holes in the small gut were sewn up. He died of acute sepsis of the retroperitoneal tissue after forty-eight hours.

Diagnosis.

Intraperitoneal damage is determined in three ways: (1) by inspection; (2) by experience; (3) by symptoms. With all possible care, and an extensive experience, and a full appreciation of the numerous fallacies, it was frequently difficult to make sure that the wound was penetrating. If it was difficult when there was an entrance and exit wound, it was still more so when there was only one wound. Shock, hæmorrhage, rigidity, or rapid pulse might be present; in some cases which were received early, there might be no such guides. It may be said that the wound of a hollow viscus has in itself no symptoms; it is hæmorrhage or peritonitis which gives the danger signal.

By Inspection.—Antero-posterior wounds are the easiest to judge. The only point to be remembered is the thickness of the flank muscles. Below the transpyloric plane a wound with the entrance on one side of the middle line and an exit near the lateral body line of the same side is very often non-penetrating, or has just opened the peritoneum. Above the transpyloric line such a wound, owing to the rounded form of the thorax, is almost certain to be penetrating. The bullet which passes in and out between the semilunar lines probably

does not open the abdomen, while the one that passes in and out outside these lines probably does. In the longitudinal direction, a bullet which enters near the costal margin and emerges above the groin will most likely traverse the abdomen. Where it is a question of single wounds, there is really no guide except the symptoms, as it is usually impossible to tell the direction of the projectile. An X-ray examination is invaluable in such cases. One case may be quoted as showing the difficulty of judging where a missile has gone. A man was shot beside the umbilicus. The shape of the wound suggested a bullet. The area was a dangerous one, so it was determined to explore the abdomen. As the wound was in a convenient situation, the exploratory incision was made through it. It was then found that the rectus muscle was torn the length of the incision. This was enlarged downwards to the pubes, the muscle being torn down to the bone, but the sheath and peritoneum were intact. The bullet had passed down behind the pubes. As there were no symptoms, nothing further was done, and the patient after an interval of several days was sent to the base doing well.

The possibility of rupture of underlying organs even if the peritoneum is intact, must be borne in mind, and it is well to err on the side of opening the abdomen.

By Experience.—This has shown that great care is needed in making a negative diagnosis, and also that it is wise to operate in doubtful cases.

Bomb wounds require special notice. The fragments into which a bomb broke on explosion were often very small, but so high was their velocity that they had very great power of penetration. The wounds might be so small and insignificant that it sometimes took real strength of mind to explore the abdomen, although the symptoms pointed to the possibility of visceral involvement. The number of these wounds made individual exploration impossible, and the only way of settling the matter was to explore the abdomen by a well-placed incision, irrespective of the situation of the wounds.

By Symptoms.—These may be enumerated as follows :— Appearance, pulse, vomiting, hæmorrhage, rigidity, pain, tenderness, subjective sensation, shock.

Usually a man hit in the abdomen looked ill. Sometimes he appeared to have no serious lesion. Often he was shocked and cold, in spite of blankets and hot water bottles, with which he was surrounded in the ambulance. Sometimes he

was apathetic and quiet, sometimes restless, either from pain or from distress. He might be blanched or of a fair colour, even normal in appearance. Before rapid evacuation was the rule the surgeons were struck by the fallaciously good facial expression of some of these cases, and often experienced a shock on taking up a man's hand to find it cold and clammy and the pulse running or even not palpable. Such cases invariably died, and operation only hastened their end.

A rapid pulse, a pulse that does not fall, or a rising pulse, are indications for operation. A slow pulse is not necessarily a contraindication unless the wound is in a non-dangerous area such as the liver. Cuthbert Wallace saw a man with four holes in his small intestine with a pulse of 60 four hours after receipt of the injury. A rapid pulse is caused by loss of blood and later on by peritonitis and sepsis. It does not seem to have any very definite connection with the number of lesions of the intestine. The pulse often falls with rest and quiet. Often a falling pulse is more an indication of the possibility of operation than a contraindication to operative measures.

From Table VII, compiled from a series of 577 cases, the general average pulse of a man wounded in the abdomen may be seen. A pulse of 100 is very common, and on the whole gives a good prognosis. A pulse of 120 seems to be a critical one, for the mortality is here rapidly mounting. Of 145 patients with a pulse over 120 only 16 recovered.

TABLE VII.

Influence of Pulse on Prognosis in a series of 577 Abdominal Wounds.

Result	Pulse-rate up to and including								
	60	70	80	90	100	110	120	130	Above 130
Evacuated to Base	1	7	23	30	108	27	37	7	9
Died ..	1	2	13	18	39	38	88	37	92
Total ..	2	9	36	48	147	65	125	44	101

In 1918 some enquiry was made to see if the mortality of patients admitted with a pulse-rate above 120 had fallen. It appeared that there had been no material change. One instance may be quoted of a series by Drummond and Taylor working at an advanced operating centre at Estaires, at a time when

all improved methods of resuscitation and anæsthesia were being employed. In 55 cases of all injuries only 15 recovered. The series included 21 abdominal wounds, with 2 recoveries. On the other hand, Major Gordon Taylor reported a series of 34 abdominal wounds with pulses over 124, with 14 recoveries, and another series of 32 cases with pulse-rates over 140 in which 12 recovered.

Wounds of the stomach nearly always lead to vomiting, and very often to hæmatemesis; but vomiting is also met with in all kinds of wounds other than abdominal. Beyond the fact that its absence shows that the stomach is most probably not involved, it has no special significance or indication.

Hæmorrhage stands out as the greatest enemy of the surgeon. It comes from various sources.

Injury to the actual wall of the stomach apparently does not cause much hæmorrhage; but damage to the vessels running on the stomach wall before they penetrate it, and to the big vessels lying on the two curvatures, does give rise to very great hæmorrhage.

There may be a fair amount of hæmorrhage from the omentum.

The small intestine wall is a source of considerable hæmorrhage, and in this way is perhaps a contrast to the stomach wall. It is not very unusual to see coils of the intestine filled with blood in addition to that which has escaped into the peritoneum.

The mesenteric vessels give rise to very considerable hæmorrhage and are probably the most common source of blood in the abdomen in the cases that come to operation. The vessels in the mesentery are unsupported by masses of muscle and for this reason one of the natural processes of hæmostasis is wanting, namely the pressure produced by the effused blood.

In the retroperitoneal tissue hæmorrhage is a source of great trouble; it often raises the posterior abdominal peritoneum so as to touch the anterior wall when the abdomen is open. It may look like a large purple intra-abdominal tumour. The surface shows cracks through which the blood oozes slowly. If left, it may become infected and the seat of gas production. If on the other hand, any attempt is made to find the bleeding point, the difficulty may be very great, even if the surgeon is successful. Whether this attempt is made must depend on the situation of the hæmatoma and the likelihood of injury to the large vessels. Probably the best thing is to leave it alone,

and to drain it through the loin if sepsis supervenes. There is often considerable shock, out of proportion possibly to the amount of blood lost. The sources of bleeding are the local vessels and sometimes the renal vessels or pelvic veins, or even the abdominal cava.

In the abdominal wall the deep epigastric artery is the usual source of the trouble; and in one case the whole abdomen was filled from a wound of this artery.

The large vessels injured are the vena cava and the iliac veins, in addition to the renal and splenic veins. The abdominal cava in one case was closed by sutures by Captain Sampson, but the patient died. On another occasion the rent was successfully brought together by forceps by Captain Taylor; the forceps were left on for the time being, and the patient was sent to the base after their removal and made a good recovery. The iliac arteries have been wounded and secured. There is no record of a wound of the abdominal aorta having been dealt with at operation, but several have been found at a post-mortem examination at a later period.

The parenchyma of all solid organs bleeds freely at first, but it is probable that if no large vessel is injured the hæmorrhage will cease spontaneously in from four to eight hours. In one case however, the splenic pulp was found still bleeding after twenty-four hours. Within limits it is not so much the amount of blood lost that causes collapse as the suddenness of the loss. Again, it is difficult to detect any definite relation between the amount of blood lost and the effect produced. A man can without detriment lose as a donor in the operation of transfusion an amount of blood which, if lost by a wounded soldier, would produce a decidedly bad effect.

Rigidity is a very constant, but varying symptom. It is seen in low thoracic injuries, in wounds of the abdominal wall, pelvic floor, and even of the thigh, and with visceral injuries.

The rigidity produced in the abdomen by low thoracic injuries is well known, and renders diagnosis very difficult, especially in cases where, as far as a study of the track indicates, the bullet may or may not have entered the abdomen. In one such case a man hit in the lower right axillary region, presented a universal rigidity of the abdominal wall, accompanied by considerable pain. His condition otherwise was not bad. It was determined to watch him, and he was put to bed and kept quiet for three hours. At the end of that time the rigidity had become board-like. There was considerable increase in his

pain, and his pulse-rate was slightly accelerated. An abdominal exploration showed that after all the abdomen was uninvolved, and that the only possible injury was a wound of the liver on its extraperitoneal surface. A piece of shell loose in the pleural cavity will also harden the abdominal muscles.

There is no royal road to a diagnosis between a thoracic and abdominal wound. It was often noticed that, if a man was placed in a semi-recumbent position, the abdominal rigidity tended to abate if the injury was only thoracic. Captain B. C. Maybury considers that superficial abdominal tenderness is often a feature of thoracic wounds.

In the wounds of the abdominal wall the rigidity is apt to be local and, as a rule, does not give rise to much confusion. Contusions of the abdomen do, however, present considerable difficulty, and in cases, which recover without operation, marked rigidity, an extremely rapid pulse and pallor may all be combined. Wounds of the pelvic floor, even when not penetrating, will produce a reflex hardness of the anterior wall, as may wounds of the upper thigh.

Injuries of both the solid and hollow viscera are accompanied by rigidity. This rigidity seems to be brought about in two ways, either as a reflex protective measure after the receipt of any wound, or from irritation of the peritoneum by blood or infection. It is largely independent of the amount of peritoneal infection, but occurs in an extreme form without any naked-eye appearance of inflammation. Under such conditions it is generally accompanied by very great pain.

Rigidity often occurs when there is blood in the abdomen, the source of which is only a wound of the mesentery or omentum. It is not, as a rule, very marked in these cases, and tends to subside with time, in contradistinction to that due to peritonitis which is progressive. Occasionally a somewhat rigid and tumid condition of the abdomen was seen in cases arriving late; such a condition was usually only a sign of hæmorrhage which had been arrested; and these cases were as a rule best left without operation.

Considered clinically, rigidity may be slight, either generally or locally. It may be confined to one part, and if this spreads, it generally means an intestinal lesion. There may be alternating rigidity; during examination the abdomen is sometimes soft and sometimes hard. This is a very puzzling condition, and its indication is not very clear; it is sometimes accompanied

by extensive injuries. The term "apprehensive rigidity" may be used to describe a condition in which, although the abdomen looks soft and moves on respiration, it at once hardens when the hand approaches to palpate. As a rule it is accompanied by no serious injury. Board-like rigidity is most puzzling when accompanied by a slow pulse. If there is extreme pain, it nearly always means that there is a wound of the intestine. Complete absence of rigidity when accompanied with obvious penetration of the abdomen, as has been pointed out by Taylor and Meyer, is often a very bad sign. One case of such a condition may be quoted. A man was hit in several places on the abdominal wall by small fragments of an aerial bomb within a few yards of an advanced operating centre. He was admitted within a few minutes of the injury. He was suffering from shock, but not cold His pulse was 130 and very poor. His abdomen was perfectly relaxed, and continued so till death, about twelve hours later. He complained of much epigastric pain. Three hours after being wounded, his condition seemed hopeless, as his pulse was small and feeble (130), and his extremities blue and cold in spite of artificial warmth. Notwithstanding his bad condition, he lingered on for many hours. A post-mortem examination showed that he had three small holes in the jejunum and about two pints of blood in the abdominal cavity. This case shows the difficulty in determining whether to operate or not. Had he been transfused, he might have stood an operation. A relaxed abdomen may exist with hollow viscera lesions and the patient be in good state.

It may be here stated that morphia in moderate doses seems to have very little effect on the state of the abdominal wall.

Pain is nearly always present in some form or another; it varies from almost uncontrollable agony to nothing more than discomfort. It usually comes on at once. There does not seem to be any particular relation between the amount of pain and the amount of injury.

Tenderness has very much the same value as the tenderness met with in penetration of the intestine due to disease. The point of maximum tenderness may coincide with the position of the gut lesion.

General Treatment.

Care of Patient in Transit.—This is largely a matter of the treatment of shock and is dealt with in Chapter III. One or two points may be noticed :—

(1) As hæmorrhage is the commonest cause of death in a situation that does not allow of temporary measures, it is worth while taking risks that would not be justified in another class of case.
(2) Morphia in moderate quantities is beneficial and not likely to complicate the diagnosis.
(3) A position that relaxes the abdominal wall is appreciated by the patient.
(4) Fluids should not be withheld ; they are both beneficial and grateful.
(5) Intravenous injections, either of blood or other fluid, should not, as a rule, be given unless operation is to be performed at once.

Question of Operation and Time of its Performance.—Experience soon showed the general advisability of operation. It became a question of excluding certain cases and of deciding the most favourable time for operation in others.

Cases excluded were :—

(1) Those in bad condition or moribund, amounting to about 20 per cent. of the total number of wounds of the abdomen.
(2) Those in which operation did not appear to be desirable, such as wounds of the liver by bullets and small fragments of metal.
(3) Those arriving late, usually after twenty-four hours, in which operation would only have spread infection. Secondary short circuits were usually fatal and suprapubic drainage useless.

X-rays.—An X-ray picture should be taken of all cases with a wound of entry only. It is only by such means that the track of the projectile and probable injury can be ascertained.

Treatment of Wounds of the Parietes.—These were treated by excision. On account of the observation by Marshall that turning a man on his face after abdominal section caused a great drop in the blood pressure, the wounds on the back of the body were usually excised before abdominal section.

Site of the Incision.—This was planned rather with a view to dealing with the probable injury than with any

reference to the entrance or exit wounds. A vertical paramedian incision was mostly used and was made sufficiently long to allow of easy work within the abdomen. Incisions in the outer part of the rectus sheath were useful where only the lateral part of the abdomen was involved. Such incisions were rather difficult of suture and divided many nerves. Towards the end of the war transverse incisions often replaced the lateral vertical incisions and were found very convenient for dealing with colic injuries.

Closure of the Incision.—The wounds were closed in layers when the condition of the patient permitted. Suppuration in the abdominal wound was always a trouble and the resulting poor scar was one of the principal reasons for placing men in the lower categories.

Treatment of the Peritoneal Cavity.—Drainage of the abdominal cavity gradually fell into disuse, and if used, was only employed for a short period. The peritoneum was usually cleaned by mopping with gauze. Flushing was not used to any great extent.

Post-operative Treatment.—Most patients were treated in the semi-recumbent position. The usual anti-shock measures were employed,* and stimulants fell largely into disuse. The usual purgatives were at first employed, but were displaced largely by the intra-muscular injection of pituitary extract, helped, if necessary, with a glycerine enema. Gastric lavage was found very useful in combating vomiting due to dilatation of the stomach. Secondary short-circuiting operations for obstruction due to matting or peritonitis were not found of value.

Mortality and Causes of Death.

Putting aside those cases that died of shock or hæmorrhage, caused either by the injury or by the operation performed in the attempt to save life, a word must be said as to the other causes of death. Injuries other than those of the abdomen were responsible for a large number. Most of the others were caused by sepsis in one form or another. Peritonitis was an obvious cause in many cases and shock was held accountable in others.

Now the symptoms produced by the virulent sepsis are clinically indistinguishable from shock, and a series of careful post-mortem examinations performed by McNee and Dunn

* See Chapter IV.

showed that retroperitoneal infection, especially in colic injuries, and gas gangrene, mostly of the posterior abdominal wall, were responsible for a large number of deaths.

The question of the time of operation was largely interwoven with the improvement in the process of resuscitation and especially with the introduction of gum saline infusion and of transfusion. On the whole there was a tendency to operate on more and more desperate cases as time went on and to shorten the time of resuscitation. The figure for the moribund cases continued at 20 per cent., but the improvement in evacuation, which reached its zenith in 1917, brought more and more dangerously wounded to the casualty clearing station.

The usual practice at the end of the war was as follows:—

(1) The cases obviously fit for operation were placed on the table as soon as possible.

(2) Those in a worse state were rested, given small doses of morphia, warmed up and supplied with fluid by either the mouth or rectum.

(3) The desperate cases were submitted to the same treatment and, if they showed any improvement by rest or warmth, were infused with gum saline or transfused immediately before or during the operation, and the injection was repeated if necessary after the operation was over.

Statistics and Results.

Mortality in the Pre-operative Days.—The expectant treatment of abdominal injuries was the method of choice in the armies of all the combatants at the beginning of the war. Gradually, on every side the operative replaced the older method.

Although it is very difficult to compare the results of the two methods, expectant and operative, some interest attaches to the figures obtained in the two periods respectively. The figures in the pre-operative periods had to be taken from the admission and discharge books of the field ambulances and casualty clearing stations, as no separate books were kept; consequently the figures could only be computed. In the second period special books were used, and the figures may be taken as approximately correct.

Into nine field ambulances over a period of six months there were admitted 1,098 abdominal wounds, with 333 deaths—a mortality of 30 per cent. In the six casualty clearing stations

during the same period there were admitted 131 cases of perforating abdominal wounds, with 73 deaths. From these figures it appears that the total mortality in the field ambulances and clearing stations was about 70 per cent.

There were also the deaths at the base in France to be added, and in the pre-operative days many such deaths occurred, which would, as far as can be judged, bring the mortality up to about 80 per cent. Makins gives the death-rate at the base among small-gut wounds as 84 per cent., and among colon wounds as 46·4 per cent. in this period. The pre-operative period covered by these figures was the first six months of 1915.

Results of Operative Treatment.—In forming an estimate of the mortality of abdominal wounds, and of the results of operative treatment, it is necessary to include all the cases, no matter at what medical unit they were treated. Results differed in different units, more or less depending upon their distance from the firing line. They also differed according to the nature of the fighting, and were nearly always worse at the end of an action than at the beginning, for the cases admitted at the end were often difficult to collect and were therefore late in arriving. Again, if times were quiet, there was plenty of time to treat all cases adequately and deliberately; at another time, when active operations were in progress, it might be only possible to pay attention to the most favourable cases. It is therefore necessary not only to reckon the operative mortality, but also to bring into account all cases which died without operation. This has been done in the following series. In the case of the moribund, the numbers are given, but details of the injury are not available in every case.

The statistics were collected in the following way. Every medical unit which was called upon to treat abdominal cases was provided with a book, in which certain headings were written down, and these were filled in at the time of operation by the medical officers. These books were provided by the Medical Research Committee.

The period during which detailed statistics, showing the results of operative treatment, are available covers the time between 1st July, 1915, and 31st December, 1916. The beginning of this period coincided with the commencement of the operative treatment.

The results of the operative treatment have also been compiled up to 30th September, 1917.

Table VIII shows the results in successive periods.

TABLE VIII.

	July 1st 1915 to Dec. 31st 1915.	July 1st 1915 to Dec. 31st 1916.	July 1st 1915 to Sept. 30th 1917.	Jan. 1st 1917 to Sept. 30th 1917.
Total cases	511	1,288	2,127	839
Moribund cases	145	250	420	170
Total mortality, excluding moribund	45·8	50·06	50·02	49
Total mortality, including moribund	61·25	60·2	59·9	59·5
Considered with view to operation	366	1,038	1,707	669
Operation not thought necessary	56	73	102	29
Total operations	310	965	1,605	640
Total operative mortality ..	53·9	53·9	52·9	51·3
Hollow viscera	64·5	64·7	—	—
Stomach*	43·75	52·7	—	—
Small gut*	63·8	65·9	—	—
Colon*	60	58·7	—	—

* Uncomplicated by any other lesion of the alimentary canal.

The above table shows the results obtained over extending periods of time, starting from the commencement of the operative treatment. The first and latest periods can be compared in first and last columns.

The figures show no great improvement, in fact the last period, as regards total mortality, is not so good as the first. This is explained by the fact that, as time went on, more and more desperate cases reached the surgeon. It was the improved technique and improved methods of resuscitation, especially blood transfusion, that enabled him to produce what appears to have been only a slight improvement in the operative mortality. In reality the change for the better was substantial.

For the late period of the war no mass statistics are available, but from a glance at Table IX the results obtained by different operators or at casualty clearing stations can be seen, and the varying effects of changing conditions studied.

TABLE IX.

Mortality at Different Casualty Clearing Stations and Advanced Operating Centres.

No.	Surgeon.	Unit.	Period.	Location.	Year.	Mortality per cent.	
						Total.	Operative.
1	Crisp English and Haycraft	No. 1 C.C.S. ..	July–Sept. 25th ..	Chocques	1915	50·0	44·5
2	,, ,, ,, ..	,, ,, ..	July–Dec. 31st ..	,, ...	1915	54·0	45·0
3	Owen Richards and J. Fraser	Advncd. Op. Centre	Sept. 25th–Oct. 13th	Noeux-les-Mines ..	1915	82·6	48·8
4	H. H. Sampson	,, ,, ,,	6 months. Quiet period	Bac St. Maur ..	1916	56.4	52·6
5	Lockwood	No. 36 C.C.S. ..	Somme Battle ..	Heilly	1916	?	51·9
6	Walters, Rollinson, Jordan and Banks.	Advncd. Op. Centre	Somme Battle ..	Warloy	1916	?	51·0
7	B. C. Maybury and others ..	No. 9 C.C.S. ..	Somme Battle ..	Contay, 3,600 yards behind Warloy.	1916	?	80·9
8	Gerald Hughes	Advncd. Op. Centre	June 1916–March 1917	Authie	1916–17	?	58·5
9	J. Fraser	No. 33 C.C.S., 9,000 yards from line.	Quiet period ..	Béthune	1917	44·3	39·9
10	Owen Richards	No. 6 C.C.S. Evacuation very difficult	Mostly a quiet period.	Barlin	1917	68·3	62·4
11	Hamilton Drummond ..	Advncd. Op. Centre	Quiet period, 5,000 yards from line.	Estaires	1917	65·0	56·9
12		C.C.Ss. of 1st Army, far back.	Break through, April 9th–May 6th.	Béthune-Merville Sector.	1918	61·5	59·3
13	Charles	No. 42 C.C.S. ..	Period of advance Sept.–October.	Boisleux-au-Mont ..	1918	?	48·6

Rollinson has traced the history of those men who were operated on at Warloy during the Somme battle. From figures supplied by him and Major W. W. Wagstaffe and those of Table VIII, an attempt has been made to show the ultimate fate of 100 men wounded in the abdomen who had been admitted to an operating centre. The results are shown in Table X.

TABLE X.

		Died.	Recovered.						
Moribund	—	20	—						
Operated and died in C.C.S.	—	37	—						
Operated and died after leaving C.C.S. ..	—	5	—						
Operated in C.C.S. and recovered	—	—	33						
Unoperated and recovered	—	—	5						
Admitted to C.C.S. ..	100								
Died		62	—						
Recovered			38						
Discharged unfit				24					
Discharged to Duty					14				
Home Service						9			
Overseas Service							5		

Table XI shows the ultimate disposal of a series of 707 cases of gunshot wounds of the abdomen after leaving casualty clearing stations.

TABLE XI.

	Remaining in Army.		Discharged from Army Permanently Unfit.	DIED.			TOTAL.
	Total.	Returned to Firing Line.		Total.	At Base.	In U.K.	
Hollow Viscera—							
Simple Injuries ..	48	13	166	22	15	7	236
Multiple Injuries ..	30	4	55	12	7	5	97
Total Hollow Viscera	78	17	221	34	22	12	333
	23·4%	5%	66·4%	10·2%			
Solid Viscera—							
Simple Injuries ..	56	21	72	23	16	7	151
Multiple Injuries ..	10	1	25	1	1	—	36
Total Solid Viscera ..	66	22	97	24	17	7	187
	35%	11·7%	51%	14%			
Peritoneum only ..	55	15	91	6	2	4	152
	36·5%	9·8%	60%	3·5%			
Other Organs affected—							
No Operation ..	13	10	6	2	2	—	21
Particulars insufficient	2	—	8	4	4	—	14
Total	15	10	14	6	6	—	35
Grand Total ..	214	64	423	70	47	23	707
	30·3%	9%	59·8%	9·9%			

This table was compiled by tracing the ultimate destination of a certain number of men, details of whose injuries appear in Table VIII.

Table XII gives the results in cases of gunshot wounds penetrating the abdomen, discharged permanently unfit. They are classified according to disability.

TABLE XII.

		Types and Cause of Disability.			Final Disability Assessment.			
	TOTAL	Constipation and Abdominal Pain.	Pain in Wound on stooping.	Ventral Hernia present.	Disability not due to Abdominal wounds.	Disability due to Abdominal Wounds.		Died as Pensioners.
						Less than 50	50 or more.	
Hollow Viscera—								
Simple Injuries ..	71	33	15	41	11	24	36	—
Multiple Injuries	27	13	6	11	3	8	15	1
Total ..	98	46	21	52	14	32	51	1
		47%	21%	53%	14%	32%	52%	
Solid Viscera								
Simple Injuries ..	36	17	7	9	9	11	16	—
Multiple Injuries	9	1	3	—	3	3	3	—
Total	45	18	10	9	12	14	19	—
		40%	22%	20%	26%	31%	42%	
Peritoneum only ..	45	17	13	12	12	19	13	1
		39%	29%	27%	27%	41%	29%	
Grand Total ..	188	81	44	73	38	65	83	2
		43%	23%	38%	21%	30%	44%	

CHAPTER XVIII.

WOUNDS OF THE ABDOMINAL VISCERA (*continued.*)

IN the preceding chapter the subject of wounds of the abdomen has been dealt with in its general aspects. Wounds of individual viscera, both hollow and solid, and the special methods by which each viscus was treated require description in more detail.

Œsophagus.

Wounds of the œsophagus were rarely seen, while those of the pharynx and trachea were more common. The rarity of such wounds is due to the fact that antero-posterior wounds involve the spine and transverse wounds involve the great vessels. Some of the lower thoracic wounds which are accompanied by vomiting may be wounds of the œsophagus. In one case of a fatal abdomino-thoracic wound it was found that the œsophagus had been torn just as it passed through the diaphragm. Such wounds must always be dangerous, as, even if diagnosed, access to them is exceedingly difficult either by way of the abdomen or across the chest.

One case may be quoted where a man was hit in the back about the fourth right interspace. He was treated for a thoracic wound, as there were no localizing symptoms. Two days later he passed *per anum* the core of a bullet, and the day following the mantle.

Stomach.

The stomach was perforated in eighty-two cases out of 965 in which operations were performed. In fifty-five instances it was the only viscus damaged. The situation of the injury is shown in Table I.

The number of times both walls were perforated and other hollow viscera, both small and large gut, wounded is rather remarkable, when one remembers how innocuous antero-posterior epigastric wounds were supposed to be.

The fact that the posterior wall may be wounded alone, or in conjunction with the posterior surface of the transverse colon, is of importance, as neither of these places is visible unless a special search is made ; such wounds have been missed at operation.

On analysis of the 27 cases, where wounds of the stomach were complicated by wounds of other hollow viscera, it was found that the small gut was wounded in 19 cases and the colon in 13; these figures include five cases of wounds to both the colon and small gut.

TABLE I.

Wounds of Stomach.

Site of Wound.	Alone.	With other Hollow Viscera.
Anterior wall	27	8
Posterior wall	5	1
Anterior and posterior walls	14	10
Greater curvature	2	1
Lesser curvature	2	1
Cardia	2	1
Near œsophagus	2	—
Lesser curvature and posterior wall	1	—
Wall, not stated	—	5
Total	55	27

The jejunum was the part of the small gut most frequently hit, very often within a short distance of its commencement. These high injuries are especially caused by side-to-side wounds which catch the bowel as it lies high up in the abdomen in front of the kidney. When the projectile pursued a more vertical course, the ileum was also injured or injured alone.

The transverse colon was injured along with the stomach more frequently than any other part of the great gut; but parts so far distant as the pelvic colon and cæcum have also been hit. The splenic flexure escaped more often than might be expected. Sometimes, in addition to the transverse, the ascending or descending colon was wounded. Such wounds were caused by projectiles having a highly inclined side-to-side course.

In wounds of the stomach associated with wounds of the solid viscera it was found that the liver was injured in 15 cases, the spleen in five, four of which were fatal; the pancreas in three, and the kidney in four cases.

A few examples of fatal complicated injuries are those in which the anterior wall, spleen and kidney, the stomach, pancreas and kidney, the stomach, liver and kidney, the

anterior and posterior walls, transverse colon and small gut, the anterior wall, transverse colon and jejunum, the lesser curvature, descending colon and liver were wounded.

In the following cases of complicated injury, the patient recovered:—Anterior wall and cæcum, anterior wall and descending colon, lesser curvature near œsophagus and top of spleen, anterior wall and lower pole of left kidney.

The few occasions on which a stomach and spleen wound occurred, considering the close association of these viscera, are remarkable and suggest that such injury is very fatal.

The stomach affords many types of wound, nearly all easily explained by the nature of the projectile and the course it takes. Sometimes the stomach wall is exposed by the carrying away of the anterior abdominal wall. At other times prolapse of the stomach takes place, accompanied by that of the colon, small gut, and spleen.

Bullets passing in an antero-posterior direction made small perforations. Shrapnel balls caused larger perforations, the edges of which were more excoriated than was the case with bullet wounds; the larger size and rounder form of the ball caused it to bruise the wall before it burst its way through. Shell and bomb fragments made wounds commensurate with their size and shape. When the axis of the flight of the projectile was more or less parallel to the walls of the stomach, the wounds became larger, showing sometimes a linear slit, sometimes a linear slit followed by a perforation, to which the name of "note of exclamation wound" may be given. The linear type of wound was nearly always on the anterior surface. When the projectile passed in through the epigastrium and out by the axilla, the slits tended to become parallel to the greater curvature. When the missile took a more vertical course, the wounds were inclined at an angle to the greater curvature, and the anterior wall of the stomach, or its antral portion, might be almost completely divided. Projectiles hitting the greater or lesser curvature in an antero-posterior direction sometimes caused rather extensive V-shaped injuries involving both walls.

Occasionally the wound was a valvular one, preventing the escape of the contents. Bruises or cuts in the peritoneum or muscular coats were not infrequently met with. Gangrene of the wall has resulted from injury to the gastro-splenic omentum.

The mucous membrane did not pout when the wounds were small; but in the case of linear wounds it became

extruded just as it does when the stomach wall is incised in a gastro-jejunostomy.

Wounds of the stomach are accompanied by very severe hæmorrhage, which may come from the organ itself or from vessels or organs near it. The hæmorrhage, as a rule, does

Fig. 1.—Bullet wound of anterior wall of stomach. The wound extended half an inch on to the posterior wall. The right gastro-epiploic artery was divided.

not come from the actual wall, but from the vessels as they run up and down its surface. The bleeding may take place either into the stomach or into the peritoneal cavity.

Symptoms.—Vomiting is a very constant symptom; in fact, the stomach is the only viscus which almost always furnishes

this symptom. It is often surprising that vomiting is possible when the size of the wound in the organ is considered. There is sometimes an escape of gas from the wound, but no particular diagnostic value is to be attached to the presence or absence of liver dullness. The escape of contents has already been dealt with. It should be noted that bile may escape from a stomach wound.

Treatment.—The standard incision is a paramedian one. The closure of wounds of the horizontal portion is easy, but the farther to the left and the nearer they are to the cardia the more difficult does the operation become. This difficulty points to the advisability of using the transpleural route when wounds of the cardia are in question, especially if the missile has entered through the thorax and has only involved the immediate neighbourhood.

As a rule, one can tell if the posterior wall is likely to have been involved. If this is the case, or if there is any doubt, the posterior surface must be explored through the gastro-colic omentum in the usual way. The suture of such wounds may be very difficult. Wounds of the lesser curvature involving both coats are also troublesome to suture. There is no need to excise the wounds unless they happen to be very ragged. Gastro-enterostomy may be necessary in cases of wounds dividing the antral portion of the duodenum, or in some cases of narrowing of the stomach ; this should only be done in cases of very evident necessity.

Prognosis.—The maximum period of successful suture after receipt of the wound is thirty-six hours, and the prognosis depends largely on the amount of hæmorrhage that has taken place, and on the association of other wounded organs. The amount of peritonitis present does not depend very directly on the length of time between the injury and the operation.

The possibility of spontaneous recovery has already been admitted.

Secondary Complications.—A secondary hæmorrhage was not a very uncommon event, and was met with as early as the fifth day. In 1916, Colonel T. R. Elliott and Captain Herbert Henry made some important remarks on the "After-history of both Operated and Unoperated Gastric Wounds." They showed that sutured and non-sutured wounds and contusions were subject to ulceration, secondary hæmorrhage, and perforation. Secondary hæmorrhage occurred on the sixth, twelfth, and fifteenth days respectively ; death occurred on the ninth, twenty-sixth, and twenty-fifth days, the first from hæmorrhage

and the last two from peritonitis. Colonel Elliott thinks this points to the necessity of careful feeding, and especially to the withholding of extractives. Sub-diaphragmatic abscesses have been met with, but were not so common as might have been expected in the pre-operative days.

Mortality and Causes of Death.—The mortality in all cases where the stomach was wounded is 60·9 per cent In cases uncomplicated with wounds of other hollow viscera, the mortality is 52·7 per cent. In the first 500 cases of 965 operated on it was 43·7 per cent. In those complicated with lesions of other hollow organs the mortality rises to 77·8 per cent.

The increased gravity of multiple wounds of different organs is well shown, for while the stomach has a mortality of 52·7 per cent., the small intestine of 65·9 per cent., and the great gut of 58·7 per cent., the combination of such injuries shows a mortality of 100 per cent. in this series of cases.

If all the published statistics are massed, there are 138 cases in which the stomach was wounded, with 88 deaths and 50 recoveries, a mortality of 63·7 per cent. The number of cases in which the stomach was the only viscus wounded is not sufficient to furnish any reliable inference, but the deaths and recoveries are almost equal.

When the effect on the mortality of an associated wound of a solid organ is considered, the result is not so clear. Thus in 38 cases, of which 17 recovered and 21 died, there were 5 cases of liver wound among the recoveries, and 5 among the deaths. Among the deaths there were also 4 cases of injury of the spleen, 1 of the pancreas and liver, 1 of the pancreas and kidney, and 1 of the pancreas

Out of 29 fatal cases uncomplicated with injuries of hollow organs, the actual cause of death in 25 cases was shock and hæmorrhage in 15; peritonitis in 5; lung trouble in 2; and gas gangrene in 3.

Small Intestine.

In 965 cases operated upon the small gut was found wounded 363 times. In 255 instances it was the only hollow viscus wounded. In the other cases the following organs were wounded, the stomach in 19 cases and the colon in 89 cases, these numbers including 5 cases where the stomach and colon were both injured; the rectum in 4 cases; the bladder in 16 cases; the liver in 8 cases, which included 2 cases of injury to the gall-bladder; the kidney in 7 cases and the spleen in 3.

The sites of the colon wounds were as follows :—Cæcum, 13 ; ascending colon, 6 ; hepatic flexure, 7 ; transverse colon, 23 ; splenic flexure, 3 ; descending colon, 13 ; pelvic colon, 18.

There does not seem to be any great difference in the frequency with which the jejunum and ileum were wounded, though, perhaps, the figures at present available are too small to draw a comparison, as the site of the lesion has not been stated with sufficient frequency. In the case of the duodenum one may state with accuracy that it was wounded 16 times among 363 small gut injuries.

The injuries of the ileum would appear to be more serious than those of the jejunum. This is supported by the fact that cases suitable for suture were more common in the upper than in the lower part, a circumstance to be expected when the size of the tube and thickness of walls of the jejunum are compared with the smallness of the tube and the thinness of the walls of the ileum. The multiplicity of the coils in the latter also favoured more extensive injury.

The character of the small gut wounds varied in some degree with the projectile that caused them, but not to the extent that might have been expected. A bullet may inflict as severe an injury as a piece of high explosive shell. It used to be thought that a patient hit by a bullet had a better chance than one injured by a shell fragment. The war has proved this to be a mistake. As a matter of fact, the least severe wounds were caused by the small fragments of bomb and shell.

A bullet injury might be complete or incomplete, *i.e.*, it might open the lumen, or it might only score, bruise or tear the outer coats. The most common injuries were the perforations made by the bullet striking the intestine at right angles to its axis. Here there were two perforations, through which the mucous membrane pouted to form a small round rosette. Some holes were so small as hardly to admit the bullet that made them ; through such holes the mucous membrane does not pout. As the flight of the bullet became more inclined to the transverse or long axis of the gut the perforations became slits, but there were still two separate wounds. These wounds gaped somewhat, and the mucous membrane overlapped the cut muscular coat, so that a considerable mucous surface met the eye. The appearance still suggested a rosette, but with one axis longer than the other. The two slits might enlarge until the continuity of the intestine was only maintained by two narrow strands of the wall.

In other cases there was only one wound, involving different portions of the circumference of the intestine ; it might reach from near the mesenteric border to near the free margin, or involve the free margin only. In other cases the free margin was slit right back to the mesenteric border, so that only a narrow strip of wall remained. The last piece to be divided was usually the attached portion ; here there was a wide gaping wound with an extensive exposed mucous surface. In extreme

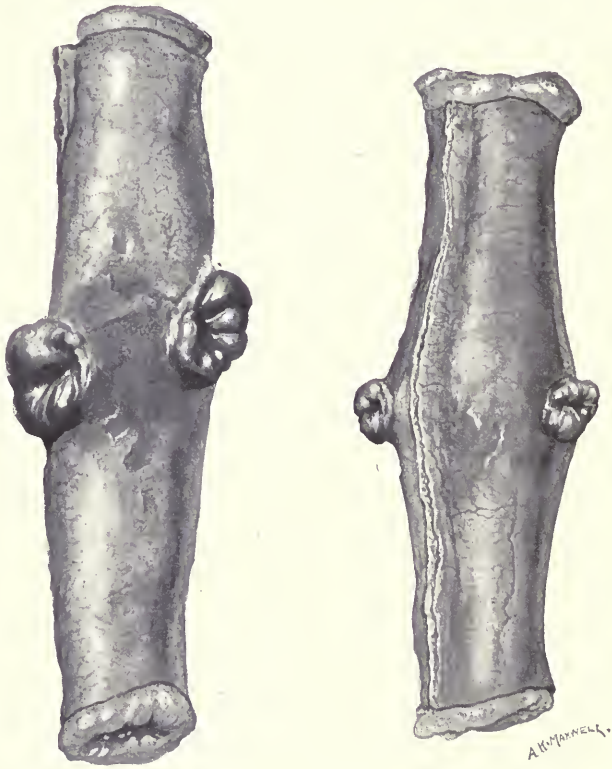


Fig. 2.—Jejunum : gunshot perforation, resected nine hours after injury. It shows the protrusion of the mucosa which usually occurs. Death.

cases the gut was completely divided. In another extreme form of injury the intestine was represented only by a long, narrow, and ragged strip of bowel.

The explanation of the transverse direction of the lesions is to be found in the looped arrangement of the small intestine, whereby the greater part of the tube lies in a vertical direction.

As a man is usually shot either from side to side or from before backwards, the missile will hit the intestine at right angles. If the bullet takes an up-and-down direction, it causes longitudinal lesions of the gut. In any one case all types of injury may be encountered.

Shell fragments caused wounds of all varieties, generally commensurate with their size. Perhaps the wounds were more

Fig. 3.—Jejunum: lacerated wounds caused by fragment of rifle grenade shown in the drawing.

irregular than those caused by bullets, and the clean transverse divisions of the gut more rare.

Shrapnel balls caused ragged perforations or tears of moderate size.

Bomb injuries often caused small multiple wounds, which were frequently collected together over a short length of the gut. The mucous membrane very often did not pout, as the hole was so small.

Lesions of the mesentery were of all sorts and varieties, from simple perforations to irregular tears. Destruction of the mesentery might occur without a lesion of the bowel and of itself necessitate resection.

Fig. 4.—Section of wound of small gut. It shows the eversion of the edge of the lesion. The mucous membrane and other coats are, except for some blood infiltration, normal right up to the cut edge.

The eversion of the mucous membrane is due to its redundancy, and, from an examination of microscopic sections, also apparently to a retraction of the longitudinal coat, according to McNee and Dunn. Microscopic examination of the wounded edges shows further that the lesion is a very local one. In fact, the appearance is no more remarkable than would be seen if the intestine had been cut with a pair of scissors; it usually consists of a blood infiltration in the neighbourhood of the wound. The mucous coat stains well and distinctly right up to the tear. There is nothing to suggest "remote disturbance" or the necessity for a wide excision of tissue.

In 124 cases the average number of lesions was 4·8, in 40 cases in which resection was performed the average number was 6·8, and in 84 cases treated by suture it was 4·1. Single lesions were the exception. The greatest number of lesions was 20, and 6 feet of intestine were successfully resected by Owen Richards. Captain John Fraser also successfully sutured 14 individual lesions and a hole in the bladder. The lesions were usually collected close together, but sometimes they were disposed in two or three groups which necessitated multiple resections. Occasionally they were scattered over the entire length of the small intestine with wide spacings.

The length of bowel involved may be gathered from the following figures, which represent in 25 consecutive cases the amount resected in inches: 30, 48, 18, 24, 30, 48, 48, 108, 30, 18, 48, 8, 20, 24, 36, 5, 48, 48, 24, 30, 48, 24, 16, 30, 24. In some of these cases, in addition, other lesions were sutured when they lay at some distance from the more severe injury.

Treatment.—A long paramedian incision was the rule, except in those cases which were dealt with when the site of the incision was discussed.

The actual operative technique in the abdomen was as follows: Any blood present must first be got rid of, and the bleeding stopped. As a rule the whole length of the small intestine must be explored, with the possible exception of those cases of side-to-side wounds involving one-half of the abdomen where a transverse incision has been used. In such cases, if the whole length of the missile track can be seen, it may be possible to dispense with the routine examination.

The cæcum or duodeno-jejunal junction is first picked up and brought out of the wound; then the intestine is inspected, taking care to look at both sides and to replace the examined part within the abdomen. If a small hole is found, and the gut

beyond it for 6 or 8 ins. is intact, the hole is sewn up. If the next lesion that is encountered is a small one, the process may be repeated. If, however, the first lesion is a large one, it is better to cover it up with gauze and a clamp, and then proceed with the examination of the whole length, for a big lesion if

Fig. 5.—Jejunum from the same case as Fig. 2: thrombosis of vessel from injury to the mesentery at two points. There were twelve perforations of the small gut. Resection of 4 ft.; end-to-end union. Death.

quickly followed by another may necessitate resection, and the amount to be resected can only be determined when the total injuries are known.

When the small intestine has been dealt with, the stomach is explored, if there is any likelihood of its being injured. The colon is dealt with last of all, as it is here that an artificial anus may be very likely necessary. If, however, a transverse incision has been used, it is best to deal with the great gut lesion first, and so limit the possibility of further spreading the infection.

Suture should be practised when possible; small discrete injuries, however numerous, should be sutured; and it is probably best if the injuries are severe or even complete, provided they are not too near together. It is also better to narrow the bowel than to resect, even if it involves a lateral anastomosis.

Resection should be reserved for cases where the bowel is practically destroyed, where there are several injuries or complete divisions close together, and where injuries extending into the mesentery or infarction of vessels give no choice.

The following figures show the length in inches resected in some successful cases taken in order: 36, 15, 36, 8, 8, 44, 12, 36, 9, 18, 8. Multiple resections in this series have always been fatal, though there have been some successful cases in other series. Table II shows the results of suture and resection in cases uncomplicated by wounds of other hollow viscera.

TABLE II.

Operation.	Evacuated to Base.	Died.	Mortality per cent.
Resection	26	87	76·9
Suture	59	71	54·6

The greater fatality of the resection cases depends largely on the initial injury, especially on the loss of blood; but there were many instances of resection in the recorded cases where the condition of the patient was at any rate fair, and yet a fatal result followed. It seems as if resection definitely increased the shock.

The old controversy regarding the best method of suture was revived and gave rise to a good deal of discussion. Circular suture was at first the most popular, but gave way

for a time in the practice of some operators to the lateral method, probably on account of the high mortality which was really unavoidable and unconnected with technique. As time went on circular suture regained its position. Failure of the suture line was very rarely the cause of death. It came to be recognized that too much time could easily be spent in meticulous adjustment of the line of union. A single line of suture was usually sufficient for closing rents in the bowel wall and many surgeons found this sufficient in end-to-end union. Some surgeons were of opinion that, owing to the nature of the internal secretion, greater care was necessary in the jejunum than in the ileum. In Table III the results of circular and lateral suture are compared.

TABLE III.

Operations.	Evacuated to Base.	Died.
Circular enterorrhaphy	18	69
Lateral anastomosis	8	18

Primary short-circuiting and enterostomy have been done at the primary operation to relieve a dilated upper segment, or as purely prophylactic measures. They are not to be recommended, though possibly useful if the upper part of the bowel is distinctly dilated from sepsis.

Secondary short circuit has been done on several occasions, but with little success.

To judge from the peritonitis present, sepsis may have made considerable headway in four hours, or it may be almost negligible after twenty-six hours.

Mortality and Causes of Death.—Table IV shows the increasing mortality of complications and Table V shows the causes of death in a consecutive series of uncomplicated resections and sutures respectively.

TABLE IV.

Site of Wound.	Evacuated to Base.	Died.	Mortality per cent.
Small gut	87	168	65·9
Small gut and stomach	4	10	
Small gut and colon	22	63	
Small gut and rectum	—	4	74·1
Small gut, stomach and colon	—	5	
Small gut and bladder	1	15	

TABLE V.

Cause of Death.	Resection.	Suture.
Peritonitis	14	14
Missed lesion	1	3
Shock and hæmorrhage	15	11
Gas gangrene of abdominal wall	5	4
Asthenia	1	1
Paralytic ileus	—	2
Pulmonary embolism	—	2
Pneumonia	—	1
Bronchitis	—	2
Gangrene of lung	—	1

As stated above, the suture line has on very few occasions shown any fault; where peritonitis supervened, it must be put down to the initial soiling of the peritoneum.

Table VI shows the average number of lesions found in the small intestine amongst cases which recovered or died after resection and suture respectively.

TABLE VI.

Operation.	Evacuated to Base.	Died.
Resection	4·1	7·1
Suture	3·45	4·27

When the comparative dangers of a wound of the duodenum, jejunum and ileum are considered, the figures available are not very adequate, since the jejunum and ileum have not been distinguished a sufficient number of times. A wound of the duodenum is a very fatal injury, as in eleven cases of wound of this viscus only two recovered. As regards the small gut, a wound of the jejunum would appear to be the least dangerous.

A wound of the bladder seems to be an extremely serious complication of the wounds of the small gut. In the series investigated there were sixteen instances of wounds of this viscus, and all but one died. This is due, partly at any rate, to the fact that when the bladder is injured the lesion of the small gut is generally very serious and is situated in the closely coiled ileum. On the other hand, half the fatal cases, which were complicated by lesions of the small gut, were treated by suture, and presumably, therefore, were not very serious. This would tend to show that there is an inherent danger in a

wound of the bladder itself. Very likely the extra time taken to deal with the lesion is a great factor in the result. In addition, there was often a fractured pelvis with these injuries.

There were three cases complicated by splenic injury, and two of them were fatal. With this exception, the solid organs do not seem to have played a great part in the mortality.

Large Intestine.

In 965 cases operated on the colon was wounded 252 times. In 155 cases it was the only part of the alimentary tract hit.

Table VII gives the number of times that the stomach and small gut suffered together with the colon. The comparatively small number of times that the splenic flexure was injured is somewhat remarkable. It may be that the explanation of this is the difficulty of differentiating between transverse and descending colons and the splenic flexure.

TABLE VII.

Site of Wound.	Wounded with Stomach.	Wounded with Small Gut.	Alone.	Total.
Cæcum	2	13	16	31
Ascending colon	—	5	36	41
Hepatic flexure	1	7	24	32
Transverse colon	4	22	15	41
Splenic flexure	—	3	18	21
Descending colon	2	9	17	28
Pelvic colon	—	18	23	41
Position not stated	4	12	6	22
Totals	13	89	155	257

When two parts of the colon were wounded the highest wound only has been given. There were five cases in which the stomach and small gut were both wounded along with the colon. The total colon wounds therefore number five less than the total given in the table.

The solid organs do not often seem to be injured at the same time as the colon. The kidney, the liver and the spleen were each hit seven times. The bladder was injured four times. The ureter was injured in two cases.

The injuries of the large intestine are really similar to those of the small gut. The differences that are to be noted are due to its larger size, the absence of coils, there being less mesentery, and its proximity, in some portion of its extent, to bone.

The large size of the tube leads to a preponderance of tears or perforations ; but instances are met with in which the whole lumen is completely divided, and this happens both in the fixed portion and in that with a mesenteric attachment. Com-

Fig. 6.—Mucous surface of caput cæcum and part of ascending colon in case quoted below. There are three fairly extensive ulcers on the posterior wall, one being in the caput. The base of each ulcer is formed by the submucous layer, and is much infiltrated with blood.

plete division is due to a collapsed condition of the gut ; the transverse, descending, and pelvic colons are the parts most frequently divided.

The absence of coils means that multiple injuries are not common, and that, when they occur, they are not so numerous

as in the small intestine. The multiple injuries are found at the bends. In one case there were six perforations, two in the ascending colon, two in the hepatic flexure, and two in the transverse colon. In another case there were three wounds in the cæcum and ascending colon, and two in the hepatic flexure. In a third case there were five wounds in the pelvic colon.

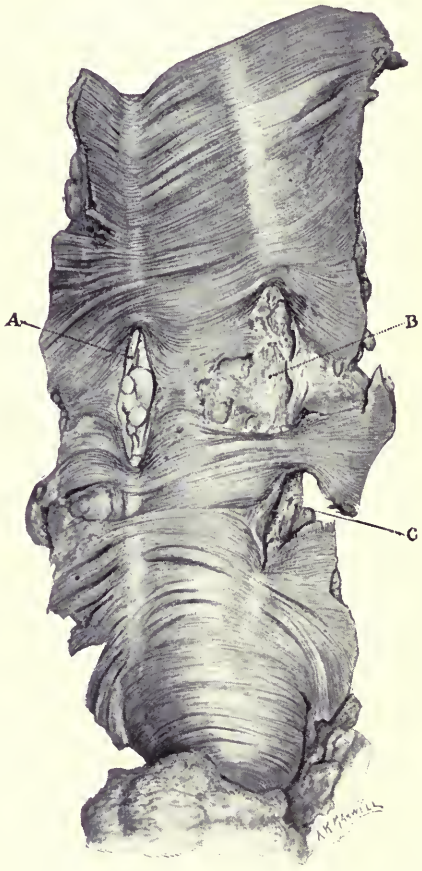


Fig. 7.—The muscular wall of the colon underlying the ulcers shown in Fig. 6. The posterior longitudinal band of muscle is torn across in two places (B and C), and the torn ends have retracted drawing with them the fibres of the circular layer. It is seen that these lesions in the muscle correspond exactly in site with the two ulcers in the ascending colon. The tear in the outer longitudinal band, marked A, was unassociated with ulceration. The arrangement of the muscular lesions in this case affords good evidence that they were produced by indirect violence, as all of them were caused by one rifle bullet.

The absence of the mesentery, over the great part of the colon, means a frequent occurrence of retroperitoneal wounds. These are difficult to find, and are largely responsible for the heavy mortality. Wounds of the partially covered portion of the small intestine, namely, the duodenum, have likewise a very large mortality.

The proximity to bone leads to wounds of the cæcum, the two vertical colons and the pelvic loop by spicules of bone; and, as has been pointed out, these injuries are apt to be overlooked, because the perforations in the peritoneum are not conspicuous.

Infarction is met with in the small intestine, but it is rather commoner in the large. The cæcum with the ileum and the descending and the iliac colons have all been found in this state.

Majors Drummond and Dunn have called attention to ulceration of the mucous membrane associated with rupture of the muscle coats. The ulceration may occur as soon as seven hours after wounding. It seems to be caused by a cutting off of the blood supply to the mucous membrane by rupture of the underlying muscle coat. It is especially interesting because the ruptured muscle may be separated from the actual track of the missile by a layer of undamaged tissue. The damage was attributed to a dragging effect produced by the projectile and transmitted through strands of fibrous tissue or to sudden impact on a gas-filled sac.

The rapidity with which the mucous membrane ulcerates after losing its blood supply is very remarkable.

These lesions may account for some of the fistulæ that form in the colon when it has apparently escaped injury.

The following case is quoted by Drummond and Dunn.

"The patient was wounded by a rifle bullet at 11.30 p.m., on 17th June, 1916, and was admitted to hospital six hours later, much collapsed. A small round entry wound was present in the left buttock, and the exit wound, which was larger and irregular, was in the right mid-axillary line at the level of the costal margin.

Laparotomy was performed shortly after admission. There was no evidence of injury of the abdominal viscera, except some hæmorrhage on the wall of the cæcum and behind the peritoneum of the right flank. Some blood-stained urine was passed a few hours later. Death occured twenty-one hours after wounding.

It was found that the wound track passed from the left buttock through the sacro-sciatic notch and the upper part of the sacrum, through the belly of the right psoas muscle, and thence between the right kidney and the ascending colon. Neither of the latter viscera had been directly touched; a layer of retroperitoneal fat a quarter of an inch in thickness intervened between the track and the colon wall. There were cellulitis and gangrene around the wound track in the retroperitoneal tissue, and films and cultures

made later from this material showed abundant gas-forming, anaërobic bacilli. The capsule of the right kidney was intact, but two subcapsular lacerations were present in the cortex on the anterior aspect of the lower pole. The ascending colon exhibited externally only some hæmorrhage on its inner side. When this portion of bowel was opened, two large areas of ulceration were observed on the posterior wall, while a third was seen in the caput cæcum (Fig. 6). The two uppermost ulcers lay almost directly over the bullet track. Each ulcer penetrated deeply into the submucous coat, but not quite through it; the bases were necrotic, and dark with hæmorrhage.

The mucous and submucosa were then dissected off from the muscular layers. By this means it was shown (Fig. 7), that underneath the middle and uppermost ulcers the posterior longitudinal band of muscle had been sharply torn across. The torn ends were widely retracted, and the circular fibres, though not lacerated, were drawn apart with them, so as to leave a complete wide gap in the muscular layers. Each of these lesions was associated with some hæmorrhage, and the exposed retroperitoneal tissue was foul and gangrenous.

A like muscular lesion was also observed in the outer longitudinal band opposite the level of the upper ulcer, but it was unaccompanied by hæmorrhage or by ulceration of the mucosa. In relation to the ulcer in the caput cæcum there was only slight tearing of the circular fibres, with some hæmorrhage."

The large intestine was often laden, but the condition of the contents rendered massive escape less frequent than it would otherwise have been; however, taken all in all, escape from the large intestine was more frequent than from the small, especially when the cæcum and ascending colon were involved.

Nature of Wounds of different parts of the Large Intestine.—There was a fair number of cæcal wounds. Most of them were small in extent, and lent themselves to suture. In other cases the wounds were so large as to necessitate an artificial anus. In one case there was bruising of a transposed cæcum. In a good many cases there was a large retroperitoneal hæmorrhage; this injury was in one instance accompanied by acute dilatation of the stomach.

All kinds of wounds are met with in the transverse colon. They vary from a simple single lesion to complete division. True antero-posterior wounds are not very common and as a rule the transverse colon is struck obliquely, the bullet passing through the anterior part of the lumen. It has already been stated that such wounds are often accompanied by lesions of the stomach and small intestine. It was owing to this association that so few cases of wounds of this portion of the colon arrived at the base in the pre-operative days.

The posterior surface was sometimes wounded, and this may be overlooked. Bleeding from the vessels supplying this portion of the bowel is fairly frequent.

It is convenient to take the ascending and descending colon together, as they have no mesentery. Both, and especially the descending colon, lie rather farther from the

lateral line than would appear. The wound may be completely intraperitoneal or extraperitoneal, or both combined. The actual lesions are perforations, slits, tears or complete divisions. Perforations are most commonly met with in side-to-side wounds, and complete division in antero-posterior wounds. All varieties may be complicated with small gut injuries. At the base, Makins noticed that wounds of the ascending colon were more common than other colon wounds; and he attributed the frequency of the ascending colon wounds, compared with those of the descending, to the latter being more often accompanied by small gut injuries, owing to the fact that the small gut overlies it. This explanation seems to a certain degree just. Out of forty-one wounds of the ascending colon, only five were complicated by small gut lesions; whereas twenty-eight wounds of the descending colon had associated small gut injuries in nine instances. The comparative rarity of descending colon wounds may also be due to the fact that the descending colon lies so deep that any bullet passsing from side to side and involving it would traverse a coronal plane situated so far back in the body as to involve the spine and great vessels. Again, the descending colon is usually much smaller than the ascending, so that it offers less of a mark for the missile.

The intraperitoneal wounds of the vertical colons are fairly easy to find and to deal with if a suitable incision is used. The extraperitoneal are very difficult to detect, and most probably are more often missed than any other. The extraperitoneal wound, which may be small and valvular, is difficult to find because it lies in a mass of areolar tissue; and the difficulty is greatly increased when this tissue is infiltrated with blood, as is so often the case.

Next to the transverse colon the hepatic flexure is the easiest of all to deal with, as it lies fairly superficially. Its form leads to multiple injuries.

The splenic flexure, from its position, is the most difficult of all the parts of the large intestine to deal with, and even with the best placed incision it is not easy to examine it properly without mobilization.

The pelvic colon is anatomically more like the small intestine than any other part of the colon, and the lesions are somewhat similar. There are slits, perforations, or complete divisions; and it is, next to the transverse colon, most often complicated with multiple small gut injuries. Fracture of the pelvis, so often associated, increases the gravity of the

case. Cuthbert Wallace has noted the great variations in position, as shown by the different situations of the wounds of the gut in different cases in which the bullet has taken a similar direction.

Symptoms.—The symptoms of intraperitoneal wounds of the large gut are similar to those of the small intestine. A great difference lies in the behaviour of the extraperitoneal wounds, where all grades of infection are met with. Sometimes there were cases of acute sepsis, with or without gas formation, which were fatal in a few hours. Such cases were often past help when they arrived at the operating centre. They were cold, blanched and clammy, and the pulse was running; in fact, their appearance often suggested acute hæmorrhage. To this class of case Captain John Fraser has given the apt name of "colon septicæmia."

The dangerous sepsis, as shown by the high mortality, of the colon anus, when formed in the vertical colons, led some operators always to make an attempt to close the bowel. Unfortunately the damage is already done when the case has come under treatment. In other cases the symptoms were less acute, or were not observed when the case arrived. Some with a small single loin wound, arriving late and left untreated did well even though a fæcal fistula formed. In others signs of intoxication and local infection appeared. Both of these may be relieved by incision, with the possible establishment of a fistulous opening. Sepsis was sometimes due to infective material carried in with the missile, and not to a communication with the bowel.

Treatment.—The fact that some unoperated colon cases did arrive at the base and recover cannot now be advanced as a ground for abstention from operative interference except in those cases which arrived late.

It may be necessary to use a paramedian incision for a general exploration of the abdomen, for the exclusion of, or for dealing with other injuries. The transverse and pelvic colons are best dealt with from such an incision, as these lesions are commonly associated with those of the small gut. It may be necessary to supplement this median incision with one toward the side of the body when either of the vertical colons is found wounded. When the missile has only traversed the loin, the horizontal incision is by far the best. The rectus sheath incision may be preferred by some for exploration of the hepatic and splenic flexures; but the association of kidney injuries with those wounds makes a horizontal incision more expedient,

as the kidney can be dealt with in the posterior extremity of the wound, whereas an attempt to remove the kidney through the anterior incision is not very convenient.

Open wounds involving the loin, and possibly involving the colon, may be dealt with by local enlargement; but, in the absence of X-rays, a median incision, to exclude other injuries, will most probably be required.

The method of dealing with the lesions is largely determined by three factors, the size of the tear, the situation of the tear, and the state of the patient, in whom other injuries may have been dealt with.

In the case of the cæcum it is better to suture wounds if possible, and provide adequate drainage if there is any possibility of an extraperitoneal wound. In wounds of the extraperitoneal part which have only been found after mobilization of the colon, even if suture is possible, it is advisable to shut off the general peritoneal cavity by a line of sutures joining the anterior surface of the bowel to the lateral abdominal wall and to provide good posterior drainage.

The transverse colon is the most easily dealt with of all the colon lesions. When the wound is large, the question is often one of whether suture or an artificial anus is the quicker method of dealing with the case, for here probably other lesions have been dealt with, and the condition of the patient is not likely to be very good.

Small lesions of the vertical colons are easily closed if intraperitoneal. Wounds involving the extraperitoneal portions of the gut are dangerous, and even if they are closed by suture adequate external drainage must be provided.

No doubt suture is the ideal method, but it is often very difficult, and in some cases impossible, owing to the loss of substance. Here the only plan is to make an artificial anus. In the retrocolic hæmatomata so often met with, it is often impossible to exclude colon injuries; these therefore must be freely drained.

The same rules apply for injuries to the hepatic flexure as to the transverse colon, the only point being that mobilization of the flexure may be necessary in order to get at the lesion.

The splenic flexure is the hardest of all to manage satisfactorily, both on account of the difficulty in reaching it, and of the mobilization necessary to find the hole. An artificial anus is often necessary.

The pelvic colon is easily dealt with in its upper portion. Care must be taken to exclude wounds on the border of the gut

uncovered with mesentery. In one case a minute fragment of bomb had entered the mesentery, which was here loaded with fat, at a little distance from the bowel, and had penetrated the bowel at the mesenteric attachment.

Table VIII shows colon injuries uncomplicated with wounds of other hollow viscera, the site of the lesion and the treatment.

TABLE VIII.

Site of Lesion.	Sutured.	Artificial Anus.	Total.
Cæcum	13	3	16
Ascending colon	25	11	36
Hepatic flexure	16	8	24
Transverse colon	13	2	15
Splenic flexure	10	8	18
Descending colon	9	8	17
Pelvic colon	16	7	23
Position not stated	—	6	6

An interesting fact in the above table is the small number of artificial ani that it was found necessary to establish at the site of a lesion in the transverse colon when no other hollow viscus had been damaged.

It seemed probable at first that proximal colostomies would have a much wider application than was found to be the case. They were, of course, useful in limiting the amount of septic absorption in cases of wounds of the vertical colons, but as has been pointed out, this tissue was already infected at the time the cases came under treatment. Most surgeons were reluctant to make an extra opening in the bowel, often at the end of a long operation. Proximal colostomy to be of any use must be complete, and it probably finds its best application in those cases of loin wounds on the left side in which sepsis develops late, and in rectal injuries. It was used considerably at the base for fæcal fistulæ developing from colon wounds when suture failed to close the rent.

Of ten proximal colostomies done at the front five were for rectal wounds and five for colon injuries distal to the transverse colon.

A transverse colostomy is to be recommended. A cæcostomy proved of little value at the front, but was useful at the base.

Mortality and Causes of Death.—The mortality of colon wounds, uncomplicated with other lesions of the alimentary

canal, is 58·7 per cent. as compared with 65·9 per cent. in the case of the small intestine. The colon mortality is greatly raised by that of the colon anus, for whereas suture of the colon has a mortality only just over 50 per cent., that of the colon anus is 73·5 per cent.

These figures must not be taken to mean that a colostomy is a necessarily dangerous operation, but only that sepsis is likely to cause death in those injuries that require a colostomy. Infection has already started where the colostomy has been performed.

It is interesting to compare the above figures with those given by Makins in the pre-operative days.

Table IX shows the difference between the mortality of small and large intestine wounds in the pre-operative and operative periods respectively, and clearly indicates that in the pre-operative period a man with a colon wound had the better chance; and this advantage still continues though the margin is narrower.

TABLE IX.

Site.	Mortality.	
	Pre-operative Period (Base).	Operative Period (Front).
	Per cent.	Per cent.
Small intestine	86·0	65·9
Great intestine	38·7	58·7

No definite comparison can be made between the different parts of the colon, as the figures were not large enough.

Table X shows the comparative mortality of different portions of the colon after suture and artificial anus.

TABLE X.

Site of Lesion.	Evacuated to Base.	Died.
Cæcum	8	7
Ascending colon	14	16
Hepatic flexure	8	11
Transverse colon	5	10
Splenic flexure	4	7
Descending colon	8	6
Pelvic colon	8	10

Wounds of the Rectum.

Table XI shows the number of wounds of the rectum in 965 cases operated on.

TABLE XI.

Viscera wounded.	Evacuated. to Base	Died.	Remarks.
Rectum alone	7	10	Three were intra-peritoneal entirely.
Rectum and small gut ..	—	4	All intraperitoneal, all sutured.

It is remarkable that the bladder was only twice wounded in conjunction with the rectum. The same observation was made in the case of the pelvic colon, which was only once wounded in association with the bladder.

Wounds of the rectum may be roughly divided into three classes: (1) those that may be said to complicate wounds of the buttocks, the ischial fossæ, or the perineum; (2) those caused by missiles that traverse the pelvic portion of the abdomen; and (3) the ulcerative lesions already described. All these are likely to be accompanied by fractures of the pelvic bones, spicules of which may wound the gut.

The missile may be a bullet or a small or large shell fragment. In the last case especially the external damage may be very great, and a large portion of the gluteal region torn away; the anus and lower portion of the rectum may be completely avulsed, or the lumen opened on one side only. If the projectile is small, the sphincter may be left intact, and the lumen of the tube perforated above that muscle. The peritoneum may or may not be opened. The danger most to be feared is septic absorption, but on the whole extensive open wounds of the buttocks did not do so badly. On the other hand, there was still considerable danger of gas gangrene in the gluteus maximus.

Wounds involving the sacrum, although not opening the gut, proved very fatal from septic infection of the pre-sacral areolar tissue. On the other hand, it happened on several occasions that pieces of shell, which had been felt protruding into the rectum on its postero-lateral aspect, were removed per rectum and recovery followed without any further surgical procedure.

The partially covered rectum may be wounded extraperitoneally or intraperitoneally, or both. Missiles that cause

such injuries take a side-to-side, antero-posterior, or semi-vertical direction. If side to side, the entrance and exit wounds lie on the postero-external aspect of the buttocks, and whether the missile catches the extraperitoneal or intraperitoneal surface, or both, depends on the plane traversed and the obliquity of this plane to the coronal plane of the body.

The side-to-side wounds were deceptive, since it might be thought from the posterior situation that they had missed the bowel.

Treatment.—The classes of cases require separate consideration.

The treatment of injuries complicating buttock wounds follows the ordinary lines of treatment of wounds in general, and consists in excising all damaged tissue. In some cases it may be possible to close the rent in the bowel or sphincter; in other cases, Makins considers that it may be beneficial to lay open the lower end of the canal by dividing the sphincter. If the peritoneum has been opened, something may be done by shutting off the abdominal cavity by sutures.

The question of colostomy must be considered, and its expediency must be determined by the difficulty or otherwise of keeping the patient clean and comfortable. It will be most called for in those cases in which the lower segment of the bowel has been carried away and the torn bowel is lying patent in the pelvis. In such cases the lumen may be closed by sutures or a purse-string ligature; this device will, at all events, tend to limit contamination of the pelvis while adhesions are forming. If a colostomy is necessary, transverse colostomy is the operation of choice, because of the ease of cleansing the opening, of fitting a belt, which will then lie on the natural line of the waist, and of subsequent closure if this is desirable.

With regard to the treatment of wounds of the rectum caused by projectiles that may have traversed the pelvis, there will not be, as a rule, much doubt that an exploratory cœliotomy is the correct procedure; but if any doubt exists, as in side-to-side and semi-vertical wounds, it will be well to err on the side of operation. If the peritoneal surface has escaped, the abdomen can be closed and the wound opened up from the exterior. Anterior wounds can often be sutured, though from their depth in the pelvis great difficulty may be experienced. A drain down to the lesion is a wise precaution in all cases. The most difficult cases of all are those which involve the rectum at the very bottom of Douglas' pouch, as here a reliable suture is often practically impossible. It has been suggested that it might be good treatment to introduce a

tube through the anus up to the site of the lesion, and to cut off the bottom of Douglas' pouch by suturing the peritoneum over it.

The question of a colostomy must be determined by the probability or not of the suture holding.

Fortunately, associated bladder wounds are rare, but a simultaneous suprapubic cystostomy and a colostomy must be avoided if possible.

Protrusion of Omentum and Viscera.

By this is meant, not the exposure of the abdominal contents through a gap in the abdominal wall, but their prolapse through a wound, often comparatively small.

As would be expected, the omentum is most frequently seen in this connection. It appears in large or small amounts in wounds situated in any part of the abdomen, also in those situated in both hypochondriac regions, where it reaches the outside of the body through the interspaces or through broken ribs where one hardly would expect to see it. Sometimes, in abdomino-thoracic wounds it passes into the pleura and plugs the hole in the diaphragm. There are two methods by which it is extruded: it is either carried out by the projectile, or driven out through the entrance or exit wound by the intra-abdominal pressure. The latter is the more common.

In one case, where a shell fragment had entered above the umbilicus in the mid-line and had come out in the right loin behind the lateral line of the body, the omentum was so firmly carried into the long oblique exit wound that it required considerable force to release it; it was, in fact, strangulated within the abdominal wall, though none of it showed externally.

Before operation became the rule it was usual to leave omental tags to slough off, and probably this is still the best course to pursue if the cases are seen late. If seen early, it is best to treat such cases as other abdominal wounds, and explore.

Next to the omentum, the small gut is most frequently herniated, and as in the case of the omentum it may be carried out or expelled. Sometimes a knuckle lying outside has been actually wounded; in other cases the extruded part has remained intact, while there have been numerous lesions in the small gut within the abdomen.

If the wound is seen early, the ordinary rules apply, and the abdomen should be opened and the lesions repaired; later—over twenty-four hours—it is not probable that anything can be done, but still it is better, perhaps, to explore if the condition of the patient justifies it.

Fig. 8.—Rectum showing large perforation on its anterior or vesica wall caused by fragment of shell entering over the sacral region and lodging at the base of the prostate.

The transverse colon has been seen herniated, and in one case the gut was tightly constricted in the wound; as the injury was two days old, the constriction was relieved, and an artificial anus established.

Some attempt has been made to study the movements of the omentum in abdominal wounds and some observations have been made by Drummond and Fraser. Where the wounds are in the upper part of the abdomen the omentum rolls itself up into a transverse pillow. If the wounds are in the lower part it remains spread out over the intestines. Cases as a rule were operated on so quickly that the omentum had no time to find the leak and attach itself. In the early days it was constantly found glued to the lesion, and it was not until the parts were disturbed that the contents of the upper dilated intestine escaped.

Wounds of the Liver.

In 965 abdominal operations the liver was found to be wounded 163 times, and 148 of these were uncomplicated. To these must be added 23 cases in which no operation was done, but in which the liver was almost certainly wounded.

Table XII shows the number of times different organs were injured in conjunction with the liver. It is probable that the liver was wounded in association with other organs rather more frequently than the table shows. A liver wound is often a minor complication of a much graver lesion, and in the pressure of work it is natural that only the more serious injury should have fixed itself in the operator's mind. But when allowance has been made for this, the small number of associated injuries is somewhat remarkable.

A good many cases of rupture by horse kicks were seen, but are not included in this series. Sometimes the wound was aggravated by fractured ribs driven in by a missile. The wounds are of all types, from a simple perforation or an avulsion of fragments, especially of the anterior edge, to an almost complete disruption.

The wounds were usually commensurate with the size of the projectile; thus bullets and small shell and bomb fragments made perforations or scores; larger shell fragments caused more ragged wounds. The friable nature of the liver, as would be supposed, lent itself to tearing and fragmentation; thus there might be radiating fissures from a central hole, crater-like exits, or pieces nearly or completely torn off. In a few cases a bullet produced the most extensive destruction.

A case may be mentioned in which the whole liver was shattered by a rifle bullet, and a piece 4 ins. by 3 ins. lay loose in the abdomen.

TABLE XII.

Viscus injured with Liver.	Evacuated to Base.	Died.	Result not known.
Stomach	5	6	4
,, and small gut	—	1	—
,, small gut and colon ..	—	2	—
,, and colon	—	1	—
Small gut	—	1	1
,, and colon	—	4	—
Colon	2	5	—
Kidney	3	9	2
Pancreas	—	2	—

The track of torn surface is at first ragged and bloody ; seen after twelve or twenty-four hours, it becomes a dirty yellow-brown ; and later it may be a vivid yellow colour, due to bilious staining.

The injury, to judge from microscopic sections, is usually limited to the vicinity of the wound ; and in those cases where destruction of cells is found at some distance from the wound it is most probably due to an infarction phenomenon. At any rate, these infarcted areas are by no means uncommon.

The gall-bladder and the common cystic ducts have all been wounded, but the larger bile passages do not seem to be so often wounded as might be expected.

Symptoms.—The symptoms are often slight, and there is then no doubt that expectant treatment is the right course. Sometimes the symptoms seem surprisingly severe, and Cuthbert Wallace noted two cases of tangential wounds of the liver in which the liver could not have been deeply involved and with no sign of blood in the abdomen. Both patients suffered from extreme shock ; one died. In two other cases which were not operated on, men with pulses of 160 recovered.

There are the usual signs of abdominal injury. Hæmorrhage was not altogether commensurate with the size of the wound, and its amount largely depended on whether a big vein had been opened or not ; if not, bleeding usually ceased spontaneously in from six to ten hours.

Secondary hæmorrhage was seen at the base, as a rule. According to Makins, " It is always associated with sepsis:

The advent of such hæmorrhage is commonly accompanied by pain, distension of the belly, rise of temperature and acceleration of the pulse, associated with pallor, restlessness and a rapid loss of strength. With these general symptoms a localized swelling usually develops, if the patient survives the immediate loss of blood, and this may be indistinguishable from a secondary abscess."

An escape of bile into the abdomen is sometimes met with. In one case a biliary peritonitis was found at the primary operation and ended fatally; no hollow viscus had been wounded. Makins mentions one case in which a collection of bile in the pelvis required operation on the eighth day;

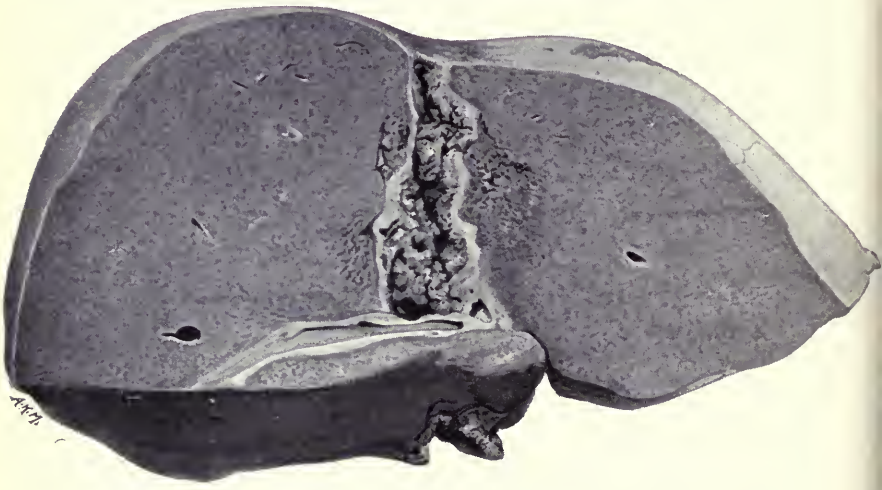


Fig. 9.—Penetrating wound of liver caused by a fragment of shell

the case ended fatally. In this case the bile came from the hepatic duct. Usually the bile does not escape from the torn liver surface to any extent and need not be feared. It may, however, stain the dressings a brilliant yellow. Bile is also met with in the pleura in abdomino-thoracic wounds without any special detriment to the patient.

Jaundice of a slight and evanescent character is seen in the first few days after the wound; it has no special significance. Seen later, it is of more serious import as it implies sepsis. Makins remarks that "this symptom was noted as an early sign in twelve of the thirty-seven cases. It is therefore a common sign, but it is variable in degree. In some cases it is

early and deep, in others slight and evanescent, and it is usually deepest when developing in association with serious septic infection. The fæces retain their normal colour, and deep staining of the urine is rare. Again, in fatal cases no sign of gross mechanical biliary obstruction is met with. These features raise the question of the actual nature of the jaundice, as does also its close resemblance to the hæmolytic jaundice often accompanying the gravest forms of general toxæmia. It is moreover, often associated with a considerable degree of fever. The sign is, of course, a classical one in the course of any case of rupture of the liver substance, whether due to gunshot injury or any other cause, and in all it is probably hæmolytic in origin. It is at any rate a striking fact that, in the obvious absence of serious infection, jaundice is either very slight, or, as in the great majority of cases, it is not observed."

Treatment.—Some cases require no operation, as there are obviously no other organs wounded, and the patient's condition is good. Many cases are operated on solely because of the possibility of injury to other organs. If such injuries could be excluded, the best results would be obtained by non-interference in the great majority of cases. When, however, the projectile has lodged and is a large one, it should be removed if at all accessible. If the projectile has entered through the thorax and lodged in the liver the transpleural route will be the best ; it is possible to deal with both the pleural and liver injury. If the abdomen has been traversed the case is not so clear, and most probably the standard paramedian incision is best in the first instance. A subcostal incision may at times be useful. As to the treatment of the liver itself, it is often unnecessary to do anything. In other cases packing is required ; suture has not proved very satisfactory. Ragged edges may be trimmed and any semi-detached portions of tissue removed. The large bile passages can be dealt with on ordinary lines by suture and drainage.

Mortality and Causes of Death.—Table XIII shows the mortality of liver wounds.

TABLE XIII.

Treatment.	Evacuated to Base.	Died.	Not known.
Operation, complicated	14	26	4
,, uncomplicated	72	32	—
No operation (no indication)	23	—	—

The mortality of the uncomplicated wounds is 29·18 per cent.

The causes of death at the front may be seen in the following list, which shows the clinical cause of death in a series of consecutive cases:—Jaundice and sepsis, 1; shock and hæmorrhage, 9; "biliary" peritonitis, 1; lung trouble, 4; gas gangrene, 1.

Speaking of causes of death at the base, Makins says that in twenty-five cases in which a liver wound was the principal cause of death, 60 per cent. of the cases died of sepsis and 40 per cent. of secondary hæmorrhage. Death in a certain number was also in part due to infection of the pleura.

In uncomplicated wounds, the mortality has a distinct relation to the amount of injury, both because of the quantity of blood lost and on account of the amount of injured substance. No connection has been traced between the direction of the projectile and the fatality; at the base side-to-side lesions were said to be commoner. Injuries of the big bile passages do not seem to increase the gravity to any appreciable extent.

Wounds of the Pancreas.

In 965 of the abdominal cases operated on, the pancreas was wounded 5 times. Very few of such injuries were noted. Possibly many were missed, and diagnosed as retroperitoneal hæmatoma. In addition, many might be rapidly fatal; the association of the gland with the large vessels scarcely requires mention.

The pancreas was found wounded three times with other viscera, namely: stomach, stomach and liver, and stomach and kidney. All three were fatal. It was wounded alone in two cases, one of which went to the base without symptoms.

There are no distinctive symptoms; the lesions are found at explorations, and are sometimes accompanied by fat necrosis.

In the case sent to the base the pancreas was obviously perforated by a bullet; the other cases were fatal.

Makins has published some cases of wounds of this organ which he saw at the base. He says that they were discovered during the performance of operations for intestinal injuries, and that the typical results of the escape of the pancreatic juice were observed. They usually proved fatal. He mentions one interesting case in which an abscess formed and was opened; the patient eventually recovered and was discharged to England. The man walked six miles after his wound. He had been detained at a casualty clearing station on suspicion of an injury to the alimentary tract.

Wounds of the Spleen.

In 965 abdominal operations, the spleen was found wounded 54 times. In 32 instances it was the only organ damaged. Table XIV shows the complication injuries of the spleen.

TABLE XIV.

Other Viscera Wounded.	Evacuated to Base.	Died.
Stomach	1	3
,, and colon	—	1
Small gut	—	1
,, ,, and colon	—	1
,, ,, ,, kidney	1	—
Colon	—	3
,, and kidney	—	2
Kidney	7	2

The injuries consisted of perforations, tears, slits in the capsule, avulsion of poles, hemisection, division of pedicle, and almost complete disruption.

Symptoms.—The symptoms are mainly those of hæmorrhage, and the diagnosis is made on these and on the position of the wound. Very often the organ is found wounded only in the course of an exploratory operation. There is nothing special about the hæmorrhage, and the damming of blood in the left loin, which has been said to be a feature of this injury in civil practice, was not conspicuous in the war. The amount of hæmorrhage varies very much, and depends mainly upon whether the vessels are injured. The splenic pulp has been found bleeding forty-eight hours after injury, but this usually ceases after ten hours.

Treatment.—Table XV shows how splenic wounds were treated.

TABLE XV.

Association with other Wounds.	Packed, sutured or left alone.		Excised.	
	Evacuated to Base.	Died.	Evacuated to Base.	Died.
With other organs	6	8	3	5
Spleen alone wounded ..	12	4	4	12
Total	18	12	7	17

There were five cases in which the spleen and kidney were both excised; two of these were fatal. The other three fatal cases of excision in complicated wounds were instances of wound of stomach and spleen, one case, and colon and spleen, two cases.

The spleen is most easily reached through an abdomino-thoracic incision. Unfortunately it is usually found wounded after the standard paramedian exploration, but it can be dealt with through this, though not very conveniently.

If associated with a thoracic wound which requires attention, it can be dealt with through the diaphragm by extending the rib incision to or through the costal margin. If, however, the

Fig. 10.—Bullet wound of spleen. The organ was almost completely divided. The vessels were ruptured in the hilum.

missile has passed across the abdomen, this incision will not suffice, though the cardiac part of the stomach and the splenic flexure of the colon can be dealt with. The association of splenic and gastric injuries is not common.

If the hæmorrhage has ceased, the organ is best left alone. Suturing or packing will control the hæmorrhage if this is going on. As a matter of fact, sutured holes are apt to bleed almost as much as a raw surface, unless the hæmorrhage is fairly free. Excision should only be resorted to if the organ is badly injured or the vessels are torn.

One point has to be borne in mind in operating on these cases, especially if associated with wounds of the renal vessels. The hæmorrhage, which very likely has been controlled or diminished by the clotting, is likely to restart in an alarming manner directly the clot is disturbed. It is therefore absolutely necessary to have everything ready for the arrest of hæmorrhage.

Mortality and Causes of Death.—Shock and hæmorrhage were the main causes of death. The mortality in uncomplicated cases was 50 per cent.

Kidney and Ureter.

The kidney was wounded 73 times in 965 abdominal injuries, that is, in about 7·5 per cent. It was the only viscus wounded in 37 instances.

Table XVI shows how in the remaining cases the wounds were complicated by wounds of other organs.

TABLE XVI.

Other Viscera Wounded.	Number of times.	Evacuated to Base.	Died.	Result not known.
Stomach	4	1	3	—
Small gut	7	4	3	—
Colon	7	3	4	—
Pancreas	1	—	1	—
Liver	14	3	9	2
Spleen	12	8	4	—

The thorax was involved in a large percentage of the cases, but no statistics are available to show the exact number.

In a series of 60 cases (56 of the kidney and four of the ureter) investigated by Colonel Fullerton at the base, the pericardium and left ventricle of the heart were implicated in one case; the pleural cavity in 27, or in 42 per cent. of the cases. In

nine cases hæmoptysis was present. The liver was injured in 16 or in 26 per cent. of the cases. In two cases a liver abscess formed around a retained foreign body. In two cases the spleen was injured; cases of splenectomy at the clearing stations were excluded. The spinal cord was injured in seven cases or in 12 per cent. of the cases. The colon was injured in three cases, the small intestine in two, and the duodenum in two. The pancreas was found injured in one case. The diaphragm and

Fig. 11.—Oblique perforation of the kidney caused by a bullet. The glass rod projects from the exit aperture.

the peritoneal cavity were frequently involved. Bone injury implicating the ribs, the spinal column or the ilium may complicate the case.

The lesions of the kidney may be divided into contusions and those that are purely gunshot wounds. Some contusions were caused by kicks of horses or mules, or by cart or shunting accidents. Other contusions resulted from the blowing up of dug-outs, and were directly caused by falls of earth or balks of timber. Sometimes large shell fragments or nose caps produced the injuries. A case of contusion of the kidney, which was accompanied by persistent and extreme shock, was

the result of a fall from the foot-plate of a locomotive, the loin of the patient coming into contact with a rail; the man recovered without operation.

In some instances injuries were caused by penetrating missiles that did not actually touch the organ. Usually such injuries were limited to subcapsular bruises, superficial cracks of the capsule or fissures of the cortex.

The actual wound lesions may be perforations, scores, furrows, cracks in the capsule, avulsion or pulping of the

Fig. 12.—Comminution of the upper half of the kidney. The organ has been reconstructed by assembling a number of fragments enclosed in blood-clot.

poles, hemisection, and almost complete disruption. As is the case with other solid organs, the kidney is liable to extensive rupture. Sometimes the kidney is found lying loose, the pedicle having been ruptured; sometimes the pelvis of the kidney is alone perforated; at other times the vessels are completely divided, the ureter remaining intact. The amount of hæmorrhage depends upon whether a vessel has been injured or not; there is very often a considerable perinephric hæmatoma. In contradistinction to civil injuries, intraperitoneal hæmorrhage is very frequent. A curious case may be mentioned in which the lower pole of the left kidney was wounded in association

with the anterior wall of the stomach. In two cases both kidneys were hit by the same missile. Both were fatal; one had paraplegia.

The hilum or the parenchyma of the organ, or both may be involved. Wounds involving the hilum may implicate the vessels or the pelvis of the kidney, or both.

Division or blocking of a branch of an artery will be followed by death of the area of distribution of that branch, as the arteries supplying the kidney are terminal or end arteries though the veins anastomose. This is the case whether the injury is at the hilum or in the parenchyma. Plate XIII (*b*) shows an injury of the latter; a cone-shaped area in the cortex has died and there is also an area of necrosis round the wound. If a large branch in the hilum is involved the appearances will be as seen in Plate XIII (*a*).

Injuries involving the pelvis of the kidney allow of the discharge of urine into the peri-renal tissues and through the wound in the parietes. If the peritoneal cavity has been opened by the missile urine may leak into it, and cause peritonitis.

Wounds of the parenchyma of the kidney may be of all grades from a small perforating wound to complete disintegration. Escape of urine in the smaller wounds is not likely to take place. If the wound is large and extends into the pelvis, leakage will be present unless the kidney is so injured that its secreting function is destroyed.

The effects of the missile on the kidney will depend on the direct damage caused by the missile; the damage due to interference with the vascular supply; the damage resulting from pressure of hæmorrhage; and the results of sepsis. The following types of injury were noted by Colonel Fullerton in base hospitals :—

(1) Injury to a branch of the renal artery without direct involvement of the kidney itself. The effect is necrosis of the area supplied by the damaged vessel as shown in Plate XIII (*a*).

(2) Contusion of the kidney produced by the passage of a missile in the vicinity without actual contact with the organ. Ecchymosis of the substance of the kidney and fissures in the capsule have been found.

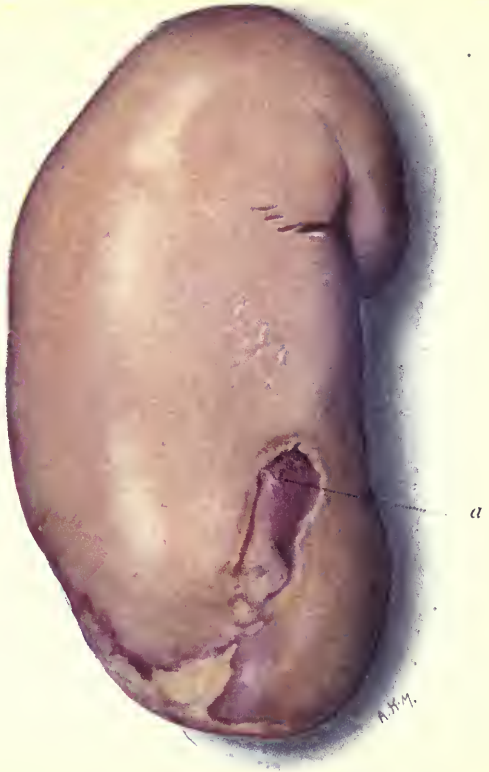
(3) Perforating wounds. (Plate XIII (*b*).)

(4) Tangential wounds.

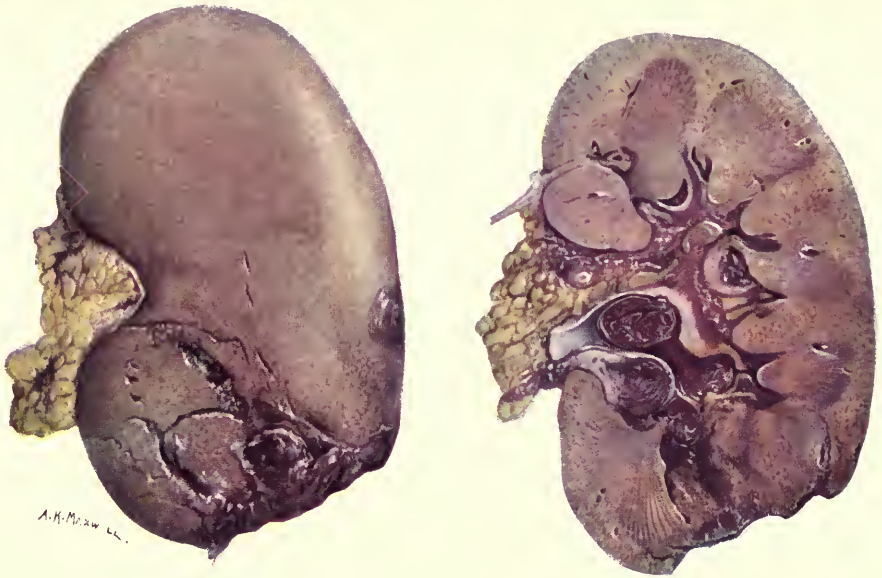
(5) Wounds destroying one or other pole, or a large area of the kidney. (Plate XIV.)

(6) Extensive destruction of the kidney.

(*a*) Injury to a large branch of the renal artery, followed by necrosis of the lower pole of the kidney. A portion of the fleshy infiltrated perirenal tissue is shown. Fifteen days after injury. *a*. Branch of renal artery ; *b*. Branch of renal vein.



(*b*) Showing perforating wound of kidney, surrounded by an area of necrosis, and an area of necrosis in cortex. Twelve days after injury. *a*. Perforating wound.



Recent shell wound of lower pole of kidney. The patient died from other wounds a few hours after being hit. The cavity of the wound is filled with blood-clot and disintegrated kidney substance. Lacerated masses of renal tissue fungate through the torn capsule. Columns of blood infiltrate the cracks, fissures, and loose areolar spaces leading towards the uninjured parts of the organ. The pelvis is filled with blood-clot.

Bowlby has shown that even in apparently trivial wounds the damage to the kidney may be more extensive than the naked-eye appearances would lead one to suspect. Bashford found that in some, at least, of the cases the injury is of a strictly local character. Estimations of the function were made by Fullerton in 20 cases and the results obtained confirm the latter view, but much necessarily depends upon the nature of the wound and the missile which causes it.

Microscopic examination shows that the destruction of kidney cells is generally limited to the immediate vicinity of the wound or of the fissures that extend from it. Infarction phenomena are not rare and, in some instances, considerable portions of the kidney may necrose.

Urinary fistula is likely to occur when the pelvis of the kidney is wounded; when a laceration of the parenchyma extends so deeply as to involve the pelvis; and when the ureter is injured. The leakage may be delayed for some days and may then be due to sloughing of a portion of the wall of the pelvis or ureter. Urinary fistula may persist for days, weeks or months. Spontaneous cure often takes place. To ascertain the extent of the damage to an injured ureter collargol or other fluid opaque to the X-rays may be used. If the fluid ascends to the pelvis of the kidney when injected into the lower part of the ureter, the inference is that the aperture in the ureter is not large, and that spontaneous cure is likely to take place.

Symptoms.—The shock is not as a rule very great, and depends largely on the amount of blood lost; this, perhaps, is peculiar, when the effect produced by the kidney blow in boxing is remembered. On the other hand, cases of kidney injury, in which the pulse was as high as 140 and the shock extreme, recover without operation. The dullness due to free fluid in the abdomen is more common than in civil injuries, and manifested itself in the right or left side according to the organ injured.

Hæmaturia was usually present, but might not occur at once. The absence of this sign is due either to suppression, or to the presence of clots or pieces of kidney in the ureter. Profuse hæmorrhage into the bladder was not common in recent injuries. Hæmaturia usually cleared up in a few days, but might persist.

Extravasation of urine was not usually marked, and was most probably limited to those cases in which the pelvis was involved.

Gas infection has occurred in the perinephric hæmatoma as well as in the muscles of the loin.

The escape of urine through the loin wound is often delayed. This may be due, like the absence of hæmaturia, to suppression or blocking of the duct. In two cases of double wound no urine was passed into the bladder, though it is doubtful whether there was not some from the loin wounds. In any case, the double wound seriously interfered with this function. It is possible, therefore, that if only one kidney is wounded, it ceases secreting. Captain Sampson, who had a considerable experience of these injuries, measured the urine after a number of excisions of the kidney; the amount was about 25 ozs. in the day. The patients were not thirsty, and did not demand water; but if they were put on forced hydropathy, the remaining kidney at once responded and passed up to 80 or 90 ozs.

In the cases at the base, Fullerton noted as signs of wounds of the kidney hæmaturia, which might be microscopic, moderate or profuse, and urinary fistula; and in addition, shock, anæmia, vomiting, tenderness and rigidity of the abdominal wall, abdominal distension, dullness in the flanks, a tumour in the flank of the affected side, and fever might also be present.

The three main complications of injuries to the kidney and ureter as seen at the base were sepsis, secondary hæmorrhage and urinary fistula. In addition, retention of urine, cystitis and fæcal fistula have been seen.

Sepsis was favoured by the following factors:—

(1) A large amount of blood extravasated into the perirenal tissue. A feature of almost constant occurrence in gunshot wounds of the kidney was the large hæmatoma which formed in the perirenal tissues.

(2) A certain amount of necrosis of gland tissue in the immediate vicinity of the wound owing to the absence of collateral circulation.

(3) Contusion or other injury to the colon.

The factors favouring the occurrence of secondary hæmorrhage were the blood supply being out of all proportion to the size of the organ; the blood-pressure being liable to frequent and sudden changes; and the necrosis which took place round the track of the missile.

Bleeding might occur into the peritoneal cavity, the perirenal retroperitoneal tissues, through the wound in the parietes or into the bladder. Secondary hæmorrhage took place in 13 cases out of a series of 56 cases of renal injury reaching the base.

In 10 of these nephrectomy was performed with three deaths. In another case death was due to other wounds. The date of onset of bleeding varied from the third day to the fifth week. It was most frequent between the tenth and fifteenth days.

Treatment.—It is very rare for any contusion of the kidney to call for active interference. The hæmorrhage is rarely excessive, usually extraperitoneal and quickly ceases. Even in the case of penetrating wounds there were many that did not require operative treatment. Small missiles often caused no symptoms save that of a moderate hæmaturia; a good pulse and a soft abdomen showed that the treatment might be expectant. Even when a comparatively large wound of the loin was present, operative treatment might often be confined to a local cleaning operation and the provision of drainage if the symptoms of hæmorrhage and peritoneal involvement were absent.

In other cases, because of hæmorrhage or because there is a probability of damage to hollow viscera, an exploration is necessary.

The actual treatment of the organ will naturally depend upon the amount of injury present. Speaking generally, a conservative attitude should be adopted. Cracks in the capsule and superficial fissures of the cortex, and simple perforations of the body of the organ can be safely left alone. Bleeding has often ceased by the time that the case comes to operative treatment. Larger injuries that are still freely oozing may be treated by suture. In the case of a shattered pole a local excision and the use of hæmostatic sutures are worth trial. Nephrectomy should be reserved for those cases in which the vessels are divided or the body greatly shattered. In the case of a hemisection involving the pelvis, nephrectomy is the best course as the organ is most probably damaged beyond hope of recovery, although there may be no bleeding. In some cases nephrectomy may be necessary to save life because of the impossibility of otherwise sufficiently quickly arresting hæmorrhage, although the injury to the organ itself may, after excision, prove to be comparatively slight. In deciding between nephrectomy and more conservative measures, the possibility of sepsis and a secondary hæmorrhage occurring in a damaged organ must be borne in mind.

In operative treatment the incision must largely be determined by the track of the missile and by the presence or absence of symptoms of the wounding of hollow viscera.

If the projectile has only involved the neighbourhood of

the kidney, a local exploration will be sufficient. This can be effected by the use of the transverse loin incision prolonged forward to open the peritoneal cavity if necessary. If the thorax has been involved the transpleural route is convenient. Here the lung wound can be attended to, the pleura cleaned and the rent in the diaphragm sutured. On the other hand, should the missile have passed further afield and traversed a remote portion of the abdomen, a paramedian cœliotomy will be found to be best as a primary measure.

Table XVII shows the treatment and result of operations.

TABLE XVII.

Operation.	Evacuated to Base.	Died.
Kidney explored	25	7
Nephrectomy (uncomplicated)	2	3
,, (spleen wounded)	3	—
,, (liver wounded)	1	1
,, (bladder wounded)	—	1
,, (colon wounded)	—	1
,, (and splenectomy)	3	2
	9	8

The method of treatment adopted in the cases enumerated under "kidney explored" was packing, suture, or nothing, the actual procedure depending on whether the organ was bleeding or not. A loin drain was used in many cases. In a large number of instances it is probable that the cases would have recovered without operation, which had to be undertaken to exclude other injury.

In these cases the kidney was considered the principal wound, and so the operation is entered under this head; the kidney was found wounded in many other cases in the course of an abdominal exploration, but these cases are not shown in this table. The organ was wounded seventy-three times, and the difference between this number and the number shown in this table represents the number of times that the kidney wound was a secondary consideration.

As in splenic injuries, the hæmorrhage from wounded kidney vessels is very liable to restart with alarming rapidity directly the clots are disturbed. The number of kidney wounds treated at an advanced operating centre seems to have been larger than in the casualty clearing station. This is most probably due to the fact that the cases arriving earlier had not suffered so much from hæmorrhage.

At the base, cystoscopy and radiography were employed to determine the extent of injury and the indications for treatment. Cystoscopy was employed to determine (1) the effect of a wound on the function of the injured kidney; (2) the presence and condition of the kidney of the opposite side; (3) whether the injury was confined to one kidney in transverse wounds; (4) the extent of the injury in wounds of the ureter; and (5) by the aid of the ureteral catheter combined with radiography, the position of retained missiles relative to the kidney or ureter.

The cases investigated as regards the function of the damaged organs showed complete recovery in eight days, or less in a few; some disturbance of function as indicated by a diminished specific gravity on the affected side, or some alteration in the permeability of the organ to dyes such as indigo-carmine or phenolsulphone phthalein in a fair proportion; and in some the presence of blood, pus, albumin and micro-organisms in the urine obtained from the affected side. All the cases were examined within two months of being injured.

X-ray examination is of the greatest service in accurately locating foreign bodies and enabling the surgeon to form an idea as to their course and the structures likely to have been injured by their passage. The opaque ureteral catheter combined with stereoscopic radiography was used to locate the position of the foreign body relative to the kidney or ureter.

Reconstruction of the track of the missile by a combination of radiography and sectional anatomy will give valuable information. In the cases seen at the base the most usual route of approach of a missile to the kidney was posterior or postero-lateral, just below the ribs; the route through the chest wall came next in frequency; transverse wounds came next, while the route from before back through the abdominal cavity was the least frequent.

With regard to the treatment of secondary hæmorrhage at the base, if the case admits of temporizing the indications are to control sepsis in the wound if possible, and to provide absolute rest with the avoidance of drugs or diet likely to increase the blood flow through the kidney. If grave anæmia is present blood transfusion should be employed and the affected kidney dealt with at once by operation. If cystoscopical examination has demonstrated the presence of a sound kidney on the opposite side, most surgeons recommend removal of the affected organ, however small the wound in it may be. Less severe and

repeated hæmorrhages demand much judgment as to when to interfere. Persistent attacks of bleeding should be dealt with by operation before the patient's condition has become critical. Even trivial wounds of the kidney may be attended with grave secondary hæmorrhage though the appearance of the wound in the parietes does not suggest severe sepsis. If there is any doubt as to the integrity of the organ of the opposite side, the surgeon may be driven to adopt conservative measures, such as wedge-shaped excision of the affected area with accurate suture of the resulting gap. Whether similar conservative methods are justifiable in other circumstances must be left to the experience and judgment of the operator. In all cases, clots in the bladder, if present, should be removed. This can readily be accomplished by the use of Bigelow's evacuator.

With regard to the treatment of urinary fistula, under expectant treatment many cases undergo spontaneous cure. In persistent cases plastic operation or nephrectomy may be required.

Mortality and Causes of Death.—In thirty-seven uncomplicated cases, there were ten deaths. Shock and hæmorrhage were by far the most common causes at the front. Associated wounds of the liver and kidney seem to constitute a very dangerous combination. Gas gangrene in the muscles of the loin and in the perinephric hæmatoma caused death in some cases.

The chief causes of death in injuries to the kidney and ureter as seen at the base were sepsis and secondary hæmorrhage. Out of a series of 60 cases reaching the base (56 of the kidney and four of the ureter) 16 died, a mortality of 26·6 per cent. Most of these were, however, complicated by other severe injuries. Thus, five cases had spinal injury, one had injury to the pancreas, one had multiple wounds and a hæmothorax, one had injury to the pleura, pericardium, heart and spleen. In two cases the immediate cause of death was peritonitis, though one had also an injury to the heart. One died of intraperitoneal secondary hæmorrhage unconnected with the kidney. One case died of infected hæmothorax and subphrenic abscess, and one of shock and early continuous oozing of blood from the kidney through the external wound.

Out of the thirteen cases of secondary hæmorrhage from the kidney, four died. Three of these were treated by nephrectomy. In the fourth case other severe wounds were present.

The ureter was not very frequently injured, but those

cases that came under treatment did well. The injury was found in the course of an exploratory cœliotomy. Suture or drainage were the methods employed. The feature of these wounds is the escape of urine externally.

Wounds of the Bladder.

The bladder was perforated forty-five times in the series of 965 cases operated on. In twenty-five instances it was the only organ injured.

The small intestine was the organ most frequently wounded in association. It is remarkable how seldom the pelvic colon or rectum was perforated at the same time as the bladder. The pelvis was fractured in a large proportion of cases.

TABLE XVIII.

Bladder Wounds.

Association with other Wounds.	Evacuated to Base.	Died.	Result not known
Small gut (resection), intraperitoneal ..	—	5	—
,, (suture), one extraperitoneal	1	6	—
,, (resection), colon anus ..	—	1	—
,, ,, rectum (suture) ..	—	1	—
Colon*	—	2	1
Rectum, extraperitoneal	—	1	—
Bladder alone injured (extraperitoneal) ..	9	11	—
,, ,, ,, (intraperitoneal) ..	2	3	—
Total	12	30	1

* Transverse colon, 1 ; pelvic colon 1 ; wound of bladder extraperitoneal, 1.

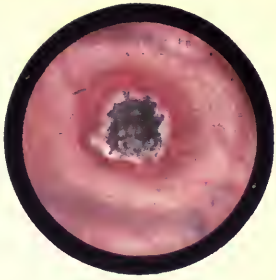
The injuries may be either intraperitoneal or extraperitoneal, or both. The intraperitoneal lesions—perforations, tears or slits—are very often not extensive. The extraperitoneal wounds, often accompanied by much hæmatoma, are slits or tears. They are usually situated at the sides of the bladder, and are often caused by bony spicules. There is only one instance in this series where the rectal surface was wounded. It is also remarkable how few have been the observed cases of prostatic wounds, so few that there is really nothing to be said about them. The combined intraperitoneal and extra-peritoneal injuries are usually caused by oblique wounds, the missiles entering by the lower lateral part of the bladder and

passing out through the peritoneal surface. Projectiles sometimes lodge within the bladder, and cause pain at a later period. Bone spicules have also been found in the viscus. One interesting case was under the care of Captain Luker in which a projectile, passing in by the buttock, wounded the postero-external angle. It pushed a piece of cloth into the viscus and then passed on and lodged behind the pubis.

Fig. 13.—Intraperitoneal rupture of bladder. The peritoneal covering is split to a greater extent than the remaining coats of the bladder. Note the exudate due to peritonitis.

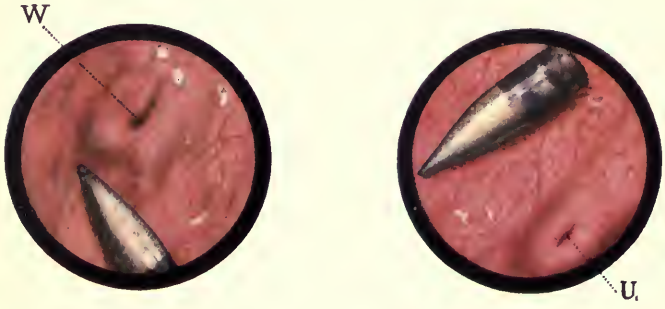
At the base the most usual form of bladder injury seen was that produced by shell. Bullet wounds came next in frequency. Shrapnel-ball was responsible for a smaller number, and bayonet wounds were rarely encountered. In one case the bladder was ruptured by a fall of earth on the abdomen (Fig. 13). The most frequent point of entry was the buttock, 34 out of 53 in Colonel Fullerton's series of cases. The suprapubic route was comparatively rare. Other routes were through the thigh, the groin, the iliac region and the

(*a*) Contusion of bladder wall produced by shrapnel ball. Ecchymosis, with large adherent clot.



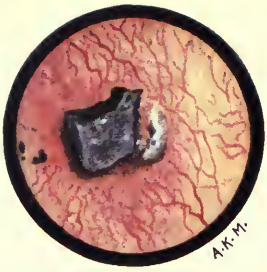
(*b*) Wound of bladder wall behind trigone, produced by shell. Localised cystitis.

(*c*) Sigmoidoscopic view, nine days after injury, of anterior wall of rectum, showing recto-vesical fistula, 2½ inches from anus, produced by a bullet which passed transversely between bladder and rectum. Note the central slough and the surrounding inflamed area. Recovery without operation.



(*d*) Wound of entrance and bullet in bladder. Moderate degree of cystitis. *W*—Wound ; *U*— Ureteric orifice.

(*a*) Two small fragments of shell in bladder. Patches of ecchymosis on mucous membrane.



(*b*) Shell fragment in bladder. Slight degree of cystitis.

(*c*) Scar on posterior wall of bladder after a wound by shrapnel ball. Mild degree of cystitis, and a few flecks of muco-pus.

CLOTH.

MISSIL

(*d*) Large piece of shell ulcerating through bladder wall. Note the adherent sloughs and the surrounding cystitis.

sacral or coccygeal region. Bayonet wounds sometimes reached the bladder through the perineum. They were then caused by the patient impaling himself upon a fixed bayonet. Wounds involving the bladder were occasionally through and through, but most had a blind extremity in the pelvis or some more distant region. The majority followed an oblique course, a few were antero-posterior, and transverse wounds were occasionally seen. By sectional anatomy combined with radiography valuable information can be obtained as to the course of the missile and the organs probably involved.

The foreign body was retained in 33 out of the 53 cases reported by Colonel A. Fullerton and it had lodged in the bladder. The missile may contuse the bladder without entering it (Plate XV (*a*)); it may lodge in the bladder wall (Plate XVI (*d*)); or enter its cavity (Plates XV (*d*), XVI (*b*), and XVI (*a*)); or it may make a second opening and emerge to lodge in the pelvis or overlying soft parts, or to escape from the body altogether.

The entrance wound in the parietes may be large, but is frequently of small size and comparatively insignificant on superficial examination. The length of the track may be six inches or more. The wound is usually of the nature of a long fistula from which urine, and sometimes fæces, are discharged. The exit wound in the parietes, when present, varies from a small puncture to an extensive laceration. The wound in the bladder is of the most varied nature. Sometimes it is a perforation as shown in Plate XV(*b*), sometimes a tear or slit (Plate XV(*d*)), and sometimes large and ragged. There is often a good deal of ecchymosis of the bladder wall in the neighbourhood of the injury (Plate XV (*a*)). The wound in the bladder may be intraperitoneal only or it may be partly intraperitoneal and partly extraperitoneal. When entrance and exit wounds exist, one may be intraperitoneal and the other extraperitoneal or both may be intraperitoneal or extraperitoneal.

The gravity of bladder wounds is greatly increased by associated damage to adjacent structures. In Colonel Fullerton's series of 53 cases, 35, or nearly 70 per cent., were complicated by injury to intestine or bone, or both. In 26 cases, or in 50 per cent., there was a wound of some part of the large intestine, and of these 13 were also complicated by damage to bone. There were 19 cases of injury to the rectum (Plate XV(*c*)). In 22 cases, or in 42 per cent, there was damage to the bones of the pelvic girdle. Damage to the

prostate is likely to occur in wounds involving the neck of the bladder. The spine, the anterior crural and sciatic nerves, the femoral vessels, the spermatic cord, the vesiculæ seminales and the ejaculatory ducts have been damaged in wounds of the pelvis involving the bladder.

Symptoms.—These are not of great importance, as most cases are submitted to operation on principle. Intraperitoneal wounds are found in the case of an abdominal exploration. The extraperitoneal wounds may be accompanied by obvious swelling above Poupart's ligament, but this sign may be absent.

There may be hæmaturia, or micturition may be impossible. Hæmaturia also occurs with bruising of the bladder without penetration. The cystoscope was not used in cases arising in medical units in army areas, and perhaps would not be of much use in the intraperitoneal wounds, as the bladder cannot be distended.

Vomiting is not an infrequent symptom in extraperitoneal wounds, and has occurred in simple extravesical hæmatoma. It is of no great value as a symptom. Extraperitoneal wounds are often accompanied with severe constitutional disturbance, the pulse mounting to 120. This phenomenon is apparently septic in origin.

On arrival at the base shock was likely to be present when other severe injuries complicated the case. This symptom may, however, be entirely absent, even when the missile has involved other hollow viscera. Hæmorrhage was a frequent cause of death at the front. Cases with a history of severe hæmorrhage rarely reached the base. Bleeding may take place into the peritoneal cavity from the external wound, or into the bladder itself. In most cases blood is present in the urine passed or removed by catheter. In a few, however, this sign has been entirely absent. Leakage of urine, when present, is one of the most important signs of injury to the bladder. This may appear at the wound in the parietes, or be more or less concealed in the form of extravasation into cellular tissue or leakage into the peritoneal cavity. When the rectum is also injured a recto-vesical fistula usually results (Plate XV (*c*)), and urine escapes into the bowel and is discharged *per anum* or from a wound in the parietes. Retention of urine is quite common for two or three days after injury. A sudden sharp pain may occur when the bladder is struck by the missile. On arrival at the base, however, pain referred to the bladder is not a constant

feature. When cystitis supervenes, the recognized symptoms of that condition will be present. Tenderness and rigidity in the hypogastrium are signs of importance, but they may be entirely absent at first, even when the peritoneum has been injured. Fever is a common accompaniment of bladder wounds. If it persists, pelvic cellulitis, abscess formation, osteomyelitis or spreading infection to the kidney should be suspected.

In the examination of bladder wounds at the base, attention should be paid to the position and direction of the wounds. Radiography will determine the presence or absence of bone injury, and the situation of retained projectiles. Cystoscopy will discover lesions of the wall, and foreign bodies such as missiles, bone fragments, clothing, blood-clot, etc., in the cavity of the bladder (Plates XV (*a*), XVI (*a*), XV (*b*), and XVI (*c*)). Rectal examination will give information as regards wounds of the lower bowel, accumulations in the pelvic connective tissue, and palpable foreign bodies. Leakage of urine occurs as a rule independently of micturition, but may be increased during the act. In wounds of the urethra, on the other hand, when the sphincter vesicæ and compressor urethræ are intact leakage occurs only during micturition. Fluid injected at the meatus in wounds of the urethra does not enter the bladder unless the opening in the urethra is small and force is used. Hæmaturia should raise strong suspicions of bladder injury. If in doubt a measured quantity of sterile fluid may be injected into the bladder, and the amount recovered measured.

Complications.—Pelvic cellulitis, peritonitis, extravasation of urine, cystitis, epididymitis, spread of infection to the kidney, osteomyelitis and necrosis, involvement of the hip-joint, gas infection, secondary hæmorrhage, fæcal fistula, fæcal extravasation, lung complications and intestinal obstruction from adhesions are among the most important complications.

Sequelæ.—Vesical calculi may form, and are due to the deposition of urinary salts round foreign bodies or sloughs, and to the persistence of cystitis. Stricture at the neck of the bladder has been noted in a few cases. Tanton in a series of 137 cases of wounds of the bladder collected by him, reports 10 cases of pyelonephritis, in 3 of which renal calculi formed.

Treatment in Front Areas.—Intraperitoneal wounds are, as a rule, easily sutured, except those which occur at the very bottom of Douglas' pouch. The bladder should be explored for a

foreign body. Suprapubic drainage is not necessary here Catheterization for a few days may be necessary, or a catheter may be tied in, though this treatment should not be continued for long, and is not favoured by some.

Extraperitoneal wounds are treated by an incision down to the wound in the bladder, which latter may be sutured if possible, and a drain left in the space formed by the operation. If the wound in the bladder cannot be sutured, it is most probable that a drain down to the wound will be sufficient; if there is any doubt, a drain into the bladder through the wound is probably the safest course. It occasionally happens that there is urinary extravasation in an extravesical hæmatoma and the hole into the viscus cannot be found. Under these conditions it is somewhat doubtful whether the right course is to be content with an extravesical drain or to do a suprapubic cystostomy in addition. Cuthbert Wallace advocates the latter, as bad results may follow such extravasation.

In those cases where the bladder is wounded on the rectal surface it would appear well to open the bladder and suture the rent from the inside, as was done by Major Hamilton Drummond.

Treatment at the Base.—The following are the measures which are indicated for treatment :—

(1) Removal of foreign bodies, clots, etc., from the bladder.
(2) Suture of the bladder wound, if practicable. Cathelin and many other authorities advise against suture of an extraperitoneal wound. There is no difference of opinion as to the necessity for suture of an intraperitoneal wound.
(3) Excision, as far as is practicable, of the wound in the parietes.
(4) Careful attention to the perivesical and perirectal cellular tissue to prevent accumulations of urine and pus.
(5) Frequent and thorough irrigation of the bladder to prevent or control cystitis.

Intraperitoneal wounds are treated by laparotomy and suture of the intraperitoneal opening. If the suture is satisfactory it has been found unnecessary to drain the bladder either by cystotomy or by a catheter tied in. Some surgeons are, however, in favour of one or other of the latter procedures as a precautionary measure.

Extraperitoneal wounds have been successfully sutured. Failing this, free exit must be provided for the escape of urine. If suture has been performed, drainage must still be provided. Fullerton rarely performed cystotomy for extraperitoneal wounds reaching the base, and did not use a tied-in catheter, but trusted to careful irrigation of the bladder, and the provision of free drainage by the parietal wound. If the bladder becomes badly infected suprapubic cystotomy may become necessary. Legueu and Makins, however, mention cases in favour of cystotomy in place of drainage. Cathelin does not consider this necessary for bladders in which the lesion has allowed of the patients being evacuated to the base. Like many French surgeons he uses a tied-in catheter (*sonde à demeure*). If collections of urine or pus form in the pelvic connective tissue, carefully planned dissections should be made to provide a free exit at the most dependent part. If the rectum is injured and there is a large communication between it and the bladder, it may be necessary to perform colotomy. Small communications tend to close spontaneously.

Mortality and Causes of Death.—The uncomplicated bladder wounds show a mortality of 56 per cent., fourteen deaths in twenty-five cases. Shock and hæmorrhage form the causes in the majority. Fracture of the pelvis seems to increase the shock greatly, and wounds of the pelvic veins are responsible for a great deal of the hæmorrhage.

In the case of complicating small gut injuries, the picture is dismal in the extreme. There were sixteen instances with only one recovery. Most of these cases were intraperitoneal wounds, which in civil practice, and uncomplicated, are not greatly feared. It would appear that the increase in time necessary to repair the bladder, after other serious injuries have been dealt with, was able to turn the balance against the patient, for the mortality is much worse than in intestinal injuries alone.

At the base 16 deaths occurred in Fullerton's series of 53 cases, a mortality of 30 per cent. Five died of pelvic cellulitis, three of peritonitis, one of secondary hæmorrhage, two of intestinal obstruction from adhesions, one of gas gangrene, two of septic pneumonia, one of heart failure, and in one the cause of death was not stated.

Abdomino-thoracic Wounds.

The mortality of wounds increases in proportion to their multiplicity; therefore abdomino-thoracic wounds should

have a heavier mortality than either chest or abdominal wounds alone. In a series of cases the total operative abdominal mortality, excluding abdomino-thoracic wounds, was 49 per cent., while that of abdomino-thoracic wounds was 55·5 per cent. This is not such a large increase when it is remembered that chest wounds within the period before evacuation to the base produce a mortality of about 22 per cent. in themselves. Another point to be borne in mind in considering the increased mortality, presumably due to the thoracic complication, is that such thoracic wounds are accompanied by wounds in a region of the abdomen that has been shown to be especially dangerous to life.

In a series of 839 cases of abdominal wounds there were 101 cases in which the missile penetrated the thoracic in addition to the abdominal cavity. The percentage of wounds involving both cavities is therefore about 12. If only operated cases are taken into account the ratio is 550 to 70, or again about 12 per cent. According to Gordon Taylor this class of wound constitutes 9 per cent. of the thoracic wounds admitted to a clearing station.

Side wounds are mostly confined to one side of the diaphragm, though the opposite chest may be involved. Wounds low enough to involve both sides of the diaphragm have usually been fatal, though some reach hospital. In this series both sides are equally affected and show an equal mortality.

As in all abdominal wounds, shell fragments are the most frequent causal agents.

TABLE XIX.

Results in Abdomino-thoracic Wounds.

Missile.	Evacuated to Base.	Died.
Bullet	2	3
High-explosive fragments	23	47
Shrapnel ball	5	4
Grenade	2	1
Aerial bomb	—	1
Bayonet	2	1

Diaphragmatic lesions are mostly found on the sloping muscular portion. A large proportion involve only that part which is in contact with the thoracic wall. The following

figures, in a consecutive series of cases during the latter part of 1917, show the extent and form of the rent as described by the operator.

Linear tear in inches, 3, 1½, 1, 1½, 1, 1, 1, ½, ½, 1, ½, ½, ½, ½, ½, ½, ½.

Irregular hole, a series of five described as of the size of 5s., 1s., 6d., 2s. 6d., 2s. 6d., a series of eight measuring in inches 1½, 2 x 1, 2½ x 1, 2, ½, 1, 1½, ¾, and two described as small.

In ten cases the wound was described as a puncture.

The nature and extent of the lesion must depend to a certain degree upon the size and shape of the missile, and this is especially true when the projectile has a highly inclined course, as under such conditions it will probably penetrate the diaphragm at a right angle.

When the flight of the missile is more or less horizontal, it will pass through the outer part of the chest or pursue a course from behind forwards or outwards, for any great deviation from such a course in the case of a left-sided wound would result in a wound of the heart. It can be seen that in both the latter types of wounds at certain levels the axis of flight will correspond to the plane of the diaphragm.

In the case of a wound of the outer part of the chest, the sloping muscular part of the diaphragm will be cut at right angles to its fibres and a gaping hole result. When the missile passes nearer the midline and in a forward and outward direction, it will be easily seen that, at a certain level, it will coincide with the dome of the diaphragm and here again cause a long rent. This rent, being in fibrous and not muscular tissue, may not at first gape, but will easily admit the passage of abdominal viscera, when the abdominal tension is increased.

It seems, from a study of traumatic diaphragmatic hernia, that it is this last type of wound which is responsible for such cases as occurred late or were diagnosed late from time to time.

In some cases the diaphragm is torn away from its rib attachment over extensive areas. It is difficult to explain how such an injury occurred. At other times extensive though local damage is caused through fractured ribs.

Table XX shows the abdominal viscera wounded in abdomino-thoracic injuries with the results.

TABLE XX.

Organ wounded.	Evacuated to Base.	Died.
Stomach	—	4
,, and liver	1	1
,, ,, spleen	—	2
,, ,, transverse colon	—	1
,, ,, jejunum and spleen	—	1
,, ,, kidney	1	—
Jejunum	1	1
,, ,, liver	—	1
,, ,, kidney	—	1
,, ,, spleen and colon	—	1
,, ,, transverse colon	—	2
Colon	3	1
,, ,, spleen	—	2
,, ,, liver	1	2
,, ,, ,, and œsophagus	—	1
Liver	10	7
,, ,, kidney	3	3
Kidney	2	1
Spleen	6	5
,, ,, kidney	—	1
Pancreas ,, splenic vein	—	1
No viscus	3	—
Total	31	39

These complications are important because they have a direct bearing on the treatment to be adopted and the route employed. Hollow viscera were wounded 28 times in 70 cases.

Table XXI shows the number of times individual organs were wounded.

TABLE XXI.

Organ.	Frequency.
Liver	30
Spleen	18
Colon	13
Kidney	13
Stomach	11
Jejunum	6
Œsophagus	1
Pancreas	1
No viscus	3

Table XXII shows the influence of a wound of a hollow viscus on the mortality during the period January to October 1917.

TABLE XXII.

	Evacuated base.	Died.	Operative Mortality.
Hollow viscera wounded	7	21	75%
No hollow viscera wounded	24	18	42·8%
Total	31	39	55·5%

Three other series of results of abdomino-thoracic injuries complicated with lesions of hollow viscera have also been recorded in the *British Medical Journal* in December 1917, January and February 1918, and August 1919, by Gask and Wilkinson, Lockwood and Gordon Taylor. These series respectively show that 3, 8 and 11 were evacuated to the base and 10, 12 and 11 died.

Table XXIII shows the effects of wounds of lung and hollow viscera on the abdomino-thoracic mortality.

TABLE XXIII.

	Total.	Re-covered	Died.	Mortality.
* Wounds of chest, lung and abdomen	27	5	22	81·5%
All wounds of chest and abdomen above the costal margin, including the above				
Right —	51	26	25	42·7%
Left —	45	25	20	

* All cases that recovered had wounds of solid viscera only.

Organs Herniated.—In a certain number of cases on the left side some of the abdominal viscera passed through the gaps. There was herniation in eight cases in the above series, which were mostly explored in the first instance through the abdomen. According to some observers, this number of herniations is below the average. The omentum is the organ most often involved, and the first part to pass through is the left side or the gastro-splenic fold. It nearly always accompanies other organs when they are protruded. Gordon Taylor

states that, in 22 cases of abdomino-thoracic wounds associated with the wound of a hollow viscus, the stomach was herniated four times, the small gut once and the colon once. In the remainder of the cases the omentum was herniated in almost every instance. In one case, not operated upon, that died from other injuries about a week after wounding, the omentum protruded through the rent, effectually plugging it,and formed the same granular-looking, mushroom-like button that used to be seen on the abdominal wall in the pre-operative days. It was carried out by the missile, or expelled by abdominal pressure. The spleen, stomach and left part of the transverse colon were the organs next most frequently herniated. The following combinations occurred: stomach and spleen; stomach and transverse colon; stomach, transverse colon and small gut. The stomach does not in the early stage pass through unless the rent is of considerable size, but is at a later period herniated through a comparatively small rent.

Treatment.—In all cases it is very necessary to know the track of the projectile and where it has lodged. If the wound involves only the neighbourhood of the diaphragm, there is no need for a complete abdominal exploration. A transpleural incision will allow of repair to the thoracic region, and an extension of it will be a convenient way of treating the abdominal viscera.

The transpleural route came more and more into favour when the development of thoracic surgery showed that the lung and pleural cavity were as amenable to surgical treatment as the abdomen and the fear of opening the pleural sac diminished. It soon became evident that this route offered an easy way to a part of the abdomen hitherto very inaccessible. There can be no doubt that this mode of approach will, in the future, be used in civil abdominal surgery, quite apart from any thoracic lesion. Its future usefulness seems to lie in cases of disease of the lower end of the œsophagus, of the cardiac end of the stomach, of the spleen and of the splenic flexure of the colon.

Under these conditions, intratracheal anæsthesia would seem to be the anæsthesia of choice.

If the projectile has passed far into the abdomen, it is obvious that an enlargement of the transpleural incision may not suffice, and that a separate cœliotomy may be necessary. It is in these cases that the surgeon must determine whether the thoracic wound requires operation, and if it does, whether preference should be given to it or to the abdominal wound.

In making a decision certain facts have to be considered.

(1) It has been shown that the mortality is still largely dependent on the abdominal injury (Table XXIV).

(2) The chief indications that have been advanced for immediate operative treatment of a thoracic wound are (*a*) an open "blowing wound"; (*b*) a "stove-in" chest wall; (*c*) the retention in the thorax of a large missile; (*d*) a wound of the diaphragm.

In the first two of these conditions the chest injury must be dealt with first. With regard to the third condition, the missile will have usually passed out of the chest in an abdomino-thoracic wound.

In the last condition suture of the diaphragm is advocated to render respiration more easy, to retain the blood in the pleura and thus assist the arrest of hæmorrhage from the lung, and to prevent or reduce herniation.

It is still doubtful how far a wound interferes with the action of the diaphragm or if suture will restore function. It has been stated that a diaphragmatic wound is a very serious lesion in itself, but many wounds of the right leaf have done well, though unsutured, which seems to point to the fact that the actual hole in the organ is not to be greatly feared, if not large enough to transmit the underlying organs. On the other hand, most surgeons state that suture is followed by great improvement in the ease of respiration.

It is still uncertain if pressure by effused blood is a potent cause of arrest of hæmorrhage.

It is impossible to gauge the size of the hole in the diaphragm; the average size can be seen above. Large herniation does not seem to be the rule, and small ones of the omentum are not an immediate danger to life.

Although suture of the diaphragm is the ideal treatment, the universal acceptance of the transpleural route for its accomplishment as a primary measure would seem in many cases to involve a lengthening of the operation which may be prejudicial to the wounded man.

It would therefore, seem reasonable to advance the following recommendations:—

(1) That many small thoracic wounds may be disregarded.

(2) That when there is an open "blowing wound," or respiratory distress, or if the hypochondrium is alone involved, the lung condition should first be attended to and the transpleural route used to treat the abdominal lesion if possible.

(3) In other cases, the abdominal exploration should come first and the lung and diaphragmatic lesions be attended to, if advisable and if time permits.

Mortality and Causes of Death.—Table XXIV shows the comparative mortality of abdomino-thoracic wounds and their influence on the total mortality of abdominal wounds, as observed in the First Army between January and October 1917.

TABLE XXIV.

	All cases.	Abdomino-thoracic.	Excluding abdomino-thoracic.
Mortality, including moribunds ..	59·5	63·0	59·2
,, excluding moribunds ..	49·2	50·6	48·9
,, operative	51·4	55·5	50·9

The total number of cases (abdominal and abdomino-thoracic) on which this table is based is 839. The following are the results in the abdomino-thoracic cases only.

Total abdomino-thoracic cases	101
Operated and evacuated	31
Operated and died	39
Unoperated and evacuated	7
Unoperated and died	24

In this series neither suture of the diaphragm nor the trans-pleural route as a primary measure was pushed.

Table XXV shows some results by surgeons in 1918.

TABLE XXV.

Surgeon.	Cases.	Recoveries.	Recoveries per cent.
Saint	22	18	81·8
Anderson	53	42	79·2
Hancock	12	8	66·6
Gordon Taylor	75	48	64·0
Stanley	24	14	58·3
Walker	21	8	38·1
Total	207	138	66·6

Diaphragmatic Herniæ.

Considering that attention was not paid to the wounds of the diaphragm until a comparatively late period of the war, and taking also into account the number of times it must have been penetrated, the comparatively small number of diaphragmatic herniæ that have been reported is somewhat remarkable. Lockwood's contention that such wounds, if not operated on, are usually fatal will not be accepted by many ; in fact, the occurrence of traumatic hernia is against this view. The most probable explanation seems to be that many healed directly, or by means of an omental plug, and that many were not diagnosed, because not suspected. This latter supposition is supported by the increasing number reported towards the end of the war, especially in France.

Putting aside those immediate herniæ that are found at the primary operation, there are others that occur later. These may be divided into two classes, namely those that occur within a short time (intermediate) and those that come to light after a lapse of time (remote).

The intermediate variety has usually been found within ten days or so of the wound, when an abdominal operation has been called for on account of obscure symptoms or at a post-mortem examination. The remote form has been found under similar conditions up to twenty-four months after the wound.

In the intermediate variety the abdominal viscera pass through when the rent is made or soon after. In the remote form the herniation takes place at a later period.

The cases have all been left-sided. The track of the missile has usually been from behind forwards and outwards, and more or less horizontal. In the intermediate form the rent in the diaphragm is large, often irregular. In the remote form it is often much smaller, although there is considerable herniation of viscera. In the recent state the edges are soft and irregular, but later on become well defined and somewhat unyielding. The shape, whatever it was at first, becomes lenticular or ovoid ; the prolapsed viscera tend to dilate and round off the irregularities. As a rule there is no sac, but this has been described in one case, and may have been due to an incomplete division of the diaphragm.

There may be many adhesions or none. If present they are usually found at the hiatus, where there may be a few points of adherence or a complete marginal attachment. The omentum is mostly concerned. Within the pleura there are not usually many adhesions.

The amount of lung collapse is very various. Often there is a good negative pressure in the thorax in the remote variety.

Organs herniated are the same as in the immediate form, and the omentum is most often found to have passed through the hole. Of the hollow viscera the stomach seems to be frequently involved in the intermediate form, and the colon and stomach, sometimes accompanied by the small intestine, in the remote form. In the intermediate variety the stomach has been found wounded as it lay within the pleura and its contents extravasated. In the remote form it may have a very distinct hour-glass shape, the neck corresponding to the rent in the diaphragm.

In some cases the hernia is spontaneously reduced to be again protruded.

Symptoms.—These are often obscure and puzzling. In the intermediate form all that usually attracts attention is the rapidity of the pulse and respiration rates, the reason for which cannot be determined.

In the remote form the symptoms consist of abdominal pain combined with a disturbance of the gastric or intestinal function. Sudden exacerbation of symptoms followed by an amelioration points to an involvement and release of the viscera.

When the stomach is involved, disturbances connected with the ingestion of food are the most marked, and when the large bowel is prolapsed obstruction is the predominant feature.

In the gastric form there is pain on taking food, sometimes trifling, sometimes severe. There may be difficulty in swallowing but this difficulty can be overcome by position, such as a dorsal or left-sided posture. Vomiting is frequent; it may be spontaneous or purposely induced to give relief. If the hernia has been of long standing there may be great emaciation.

In the colic form there is usually a history of attacks of abdominal pain and constipation, with intervals of complete freedom from both. The intervals between the attacks are very various and often in the early stage amount to months. Later on the intervals become shorter. The patient is usually in good health and well nourished. The pain is the same as that met with in chronic obstruction, but is sometimes experienced in the left chest as well as in the abdomen. Sometimes the obstruction becomes acute.

If acute intestinal obstruction is not present the abdomen is nearly always normal. Even if the symptoms have suggested a hernia, it is possible that the physical signs may be quite

unconvincing. Whether the examination is helpful or not depends upon whether the hernia is large enough to displace or compress the lung, or whether it contains air or fluid and so gives rise to abnormal noises. As a rule, it is the stomach that produces the most pronounced physical sounds, both from its bulk and its air and fluid contents. The colon, if the obstruction is at the distal point of the involved bowel, will cause very much the same signs as the stomach.

The actual physical signs noted are as follows :—

(1) Dullness and absence of breath sounds.

(2) Feeble respiratory murmur and increased resonance.

(3) Tinkling, gurgling or splashing sounds. These occur with the colon, but are more usually found with the stomach, where ingestion of fluid may produce or increase them. There has been a difficulty in telling whether these signs originate in the abdomen or thorax. When heard they have frequently not been appreciated at their proper value.

The diagnoses actually made have embraced the following : " massive collapse of lung," " subdiaphragmatic abscess containing air," and " pneumothorax " and " hæmothorax."

X-ray examination has shown an absence of the usual lung shadow and an alteration in the position, form and motility of the diaphragmatic vault. If the stomach is the organ involved and is herniated at the moment, a bismuth meal quickly clears up the diagnosis.

Obscure abdominal symptoms in a man previously shot through the lower chest should suggest the possibility of a diaphragmatic hernia. If this possibility is borne in mind a diagnosis will almost always be made, although the physical signs are puzzling.

Treatment.—This is operative. If the diagnosis has been made, and there are no acute symptoms, the transpleural route is the best, and should be used in the first instance, though difficulties of reduction may necessitate a cœliotomy. When, however, the diagnosis is doubtful the abdomen should be opened and the actual condition ascertained.

A paramedian incision is best. There may be an absence or a perfectly obvious displacement of stomach, colon and omentum. On the other hand, all may appear normal. A manual examination of the diaphragmatic vault will quickly show the presence and site of the hernia, provided the contents are not reduced.

Care must be taken not to miss a small colic hernia. Such a hernia produces no obvious displacement of the viscera,

and may be missed unless the continuity of the transverse and descending colon be carefully traced. The approximation at the hernial opening of the proximal and distal ends of the herniated loop may lead to the belief that the bowel is continuous within the abdomen, and that the only abnormality is a highly placed splenic flexure. If there are but few adhesions reduction may be effected from the abdomen, but if there are many it will be necessary to do this by the transpleural route. A finger introduced through the rent will indicate the best position in which to perform thoracotomy. Cowell's method is to be recommended.

Even after an abdominal reduction of the hernia contents a thoracotomy may be necessary to close a rent which is not suturable from beneath the diaphragm.

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Fullerton	Gunshot Wounds of the Kidney and Ureter as seen at the Base.	Brit. Jl. Surg., 1917-1918. Vol. v, p. 248.
,, ...	Blessures du rein et de l'uretère. Conférence interalliée pour l'Etude des plaies de Guerre.	5e Session, 1918. Arch. de Méd. et Pharm. Mil., 1919. Vol. lxxi, p. 444.
,, ...	On the use of the Opaque Ureteral Catheter to localize missiles in the region of the Kidney and Ureter.	Brit. Jl. Surg., 1916-1917. Vol. iv, p. 278.
,, ...	Observations on Bladder Injury in Warfare.	Brit. Jl. Surg., 1918-1919. Vol. vi, p. 24.
Gordon Taylor ..	On Abdomino - Thoracic Wounds of Warfare.	B.M.J., 1919. Vol. ii, p. 131.
Legueu	Considérations Générales sur les Plaies de la Vessie.	Jl. d'Urol, Paris, 1917-1918. Vol. vii, p. 1.

Makins	A Study of one hundred and eleven cases of Perforating Wounds of the Gastro-intestinal canal which occurred amongst a consecutive series of 202 Perforating Wounds of the Abdomen in which the presence of visceral injury was certain.	Jl. of R.A.M.C., 1916. Vol. xxvi, p.1.
,, ...	A Study of the Symptoms and Complications of Gunshot Wounds of the Solid Abdominal Viscera.	Brit. Jl. Surg., 1915-1916. Vol. iii, p. 645.
Richards	The Pathology and Treatment of Gunshot Wounds of the Small Intestine.	B.M.J., 1915. Vol. ii, p. 213.
Tanton	Comptes rendus de la Conférence Chirurgicale Interalliée pour l'Etude des plaies de Guerre	4e. Session, Paris, 1918. Arch. de Méd. et Pharm. Mil., 1918. Vol. lxx, p. 291.
Wallace	War Surgery of the Abdomen.	Lond., 1918.
Walters, Rollinson, Jordan & Banks	A series of 500 emergency operations for Abdominal Wounds.	Lancet, 1917. Vol. i, p. 207.

APPENDICES

APPENDIX A.—TABLE I.

Admissions for Gunshot Wounds during 1914, showing the site of wound according to body area.

Site of Wound.	Western Front.*				United Kingdom.				Totals.			
	Officers.		Other Ranks.		Officers.		Other Ranks.		Officers.		Other Ranks.	
	Total.	Per cent.	Total.	Per cent.	Total.	Per cent.	Total.	Per cent.	Total.	Per cent.	Total.	Per cent.
Head	206	11·0	5,164	9·8	2	16·65	21	6·1	208	11·0	5,185	9·8
Face	90	4·8	2,460	4·7	—	—	16	4·65	90	4·8	2,476	4·7
Neck	45	2·4	824	1·5	—	—	1	0·3	45	2·4	825	1·5
Chest	127	6·8	1,933	3·7	2	16·65	16	4·65	129	6·8	1,949	3·7
Abdomen	90	4·8	1,282	2·4	1	8·35	8	2·3	91	4·8	1,290	2·4
Perineum	7	0·4	159	0·3	—	—	2	0·6	7	0·4	161	0·3
Back	48	2·5	2,254	4·3	—	—	5	1·5	48	2·5	2,259	4·2
Upper Extremity	598	31·8	20,594	39·1	4	33·35	131	38·1	602	31·9	20,725	39·1
Lower Extremity	638	34·0	17,492	33·2	3	25·0	127	36·9	641	33·9	17,619	33·2
Site not stated	29	1·5	547	1·0	—	—	17	4·9	29	1·5	564	1·1
Total	1,878	100·0	52,709	100·0	12	100·0	344	100·0	1,890	100·0	53,053	100·0

* Including Indian Troops.

APPENDIX A.—TABLE II.

Admissions for Gunshot Wounds during 1915, showing the site of wound according to body area.

Site of Wound.	Western Front.				Gallipoli.				Egypt.				Med. E.F.*				United Kingdom.				Totals.			
	Officers.		Other Ranks.		Officers.		Other Ranks.		Officers.		Other Ranks.		Officers.		Other Ranks.		Officers.		Other Ranks.		Officers.		Other Ranks.	
	Total.	Per cent.	Total.	Per cent.	Total.	Per cent.	Total.	Per cent.	Total.	Per cent.	Total.	Per cent.	Total.	Per cent.	Total.	Per cent.	Total.	Per cent.	Total.	Per cent.	Total.	Per cent.	Total.	Per cent.
Head ..	998	14·0	27,238	13·9	106	11·2	2,767	9·1	4	30·8	95	6·7	64	9·1	1,369	8·8	31	20·7	712	15·6	1,203	13·5	32,181	12·9
Face ..	483	6·8	12,899	6·6	54	5·7	1,633	5·3	—	—	68	4·8	32	4·6	741	4·7	21	14·0	436	9·6	590	6·6	15,777	6·4
Neck ..	157	2·2	4,151	2·1	34	3·6	638	2·1	—	—	40	2·8	26	3·7	362	2·3	3	2·0	123	2·7	220	2·5	5,314	2·1
Chest ..	424	6·0	8,326	4·2	74	7·8	1,605	5·3	1	7·7	82	5·8	26	3·7	679	4·3	4	2·7	75	1·6	529	5·9	10,767	4·3
Abdomen ..	295	4·1	5,264	2·7	40	4·2	947	3·1	1	7·7	27	1·9	30	4·3	492	3·2	2	1·3	62	1·4	368	4·1	6,792	2·7
Perineum ..	15	0·2	515	0·3	5	0·5	97	0·3	—	—	1	0·1	—	—	39	0·3	2	1·3	34	0·7	22	0·2	686	0·3
Back ..	365	5·1	10,829	5·5	31	3·3	1,437	4·7	—	—	75	5·3	24	3·4	824	5·3	3	2·0	85	1·9	423	4·7	13,250	5·3
Upper Extremity.	2,039	28·6	63,662	32·4	256	27·0	10,447	34·2	3	23·0	516	36·4	237	33·8	5,505	35·3	35	23·3	1,296	28·5	2,570	28·8	81,426	32·8
Lower Extremity.	2,271	31·9	61,306	31·2	339	35·8	10,728	35·1	4	30·8	509	36·0	254	36·2	5,472	35·1	43	28·7	1,479	32·5	2,911	32·6	79,494	32·0
Site not stated	78	1·1	2,265	1·1	9	0·9	258	0·8	—	—	3	0·2	8	1·1	114	0·7	6	4·0	250	5·5	101	1·1	2,890	1·2
Total ..	7,125	100·0	196,455	100·0	948	100·0	30,557	100·0	13	100·0	1,416	100·0	701	100·0	15,597	100·0	150	100·0	4,552	100·0	8,937	100·0	248,577	100·0

* Med. E.F. includes all cases not specifically stated as Gallipoli or Egyptian Force.

APPENDIX B.

Explosives used in German Shells.

1. Black powder in bursting charges of shrapnel shells.

2. *Granatfüllung* 88 (*Grf.* 88) *or Picric Acid.*—Crystalline or fine powder; bright yellow; slightly soluble in water, which it colours strongly; stains skin yellow; intensely bitter taste; replaced by T.N.T. in bursting charges of shells, but used for exploders, in the gaines of fuzes, etc. To fill shells it is melted by heat and poured in; same as English lyddite. Explosive effect slightly greater than that of compressed wet gun-cotton. Melts at 121·6° C.

Forms sensitive compounds with heavy metals, especially lead.

3. *Füllpulver* O_2 (*Fp.* O_2) *or Trotyl* (T.N.T., trinitrotoluene, trinitrotoluol, trinol, tritolo and tolite).—Crystalline, nearly white or brownish white; almost insoluble in water, but soluble in hot alcohol or benzol; either melted into the shell (cast trotyl) or "stemmed" in.

Explosive effect rather less than that of picric acid. Melts at 81°C. Does not form sensitive compounds with heavy metals.

4. *Astralite.*—Yellowish gray. Consists of a mixture of:—(1) $NH_4 NO_3$; (2) Woodmeal; (3) Dinitrotoluene with traces of T.N.T. (4) A small amount of nitro-glycerine; (5) Some nitrocellulose. Used in trench mortar shells. Fairly, but not excessively powerful.

5. *Amatol.*—Crystalline; yellow or brown; a mixture of $NH_4 NO_3$ and T.N.T. (60/40). Explosive effect powerful and fairly violent.

6. *Dinitrobenzene or Dinitrobenzol.*—Crystalline; pale yellow or nearly white when pure. Melts at 89·8°C. Very slightly soluble in water; more soluble in alcohol and benzene.

Not generally used alone in shell, its explosive properties being poor. Sometimes used mixed with $NH_4 NO_3$.

7. *Trinitro anisol.*—Greenish yellow, Melts at 64°C. when pure. Cast into the bombs and forms a soft mass of crystals with a greasy appearance. Readily decomposed by moisture giving picric acid and methyl alcohol. Will therefore attack lead. Not frequently used. Explosive effects similar to those of picric acid, but trinitroanisol is more difficult to detonate.

8. Nitrolite or Trinitroanisol and $NH_4 NO_3$; mixture found in a Minenwerfer projectile.

APPENDIX C.

Description of German Aircraft Bombs.

High explosive bombs alone are described, incendiary bombs and flares being omitted.

1. *From Naval Airships.*

These are pear-shaped with oil-hardened steel walls, the oil hardening causing the walls to break up into knife-edged pieces. The base is a solid plug made of hardened cast steel. The pieces into which these bombs break upon explosion vary in size and shape from 6 in. square downwards, are $\frac{3}{16}$ in. thick, and are of a light brassy bronze colour. The edges are very jagged and have particularly good cutting properties. The line of fracture is almost always at an angle of 45° to the surface of the piece. In the case of the 660 lb. bomb, the pieces resemble in general outline and cutting properties those described above except that they may be larger and are $\frac{1}{2}$ in. thick. The following table gives further particulars of these bombs:—

Weight of bomb in lbs.	Thickness of wall in inches.	Base plug.		Height in feet and inches.	Diameter in inches.
		Diameter in inches.	Weight in lbs.		
50—60	$\frac{3}{16}$ in.	—	—	24 in.—36in.	12 in.—18 in.
110	$\frac{3}{16}$ in.	4	6½		
220	$\frac{3}{16}$ in.	7	17	—	—
660	½ in.	9	27	5 ft. 6 in.	22

2. *From Military Airships.*

These are always spherical in shape and vary in size from 30 lb. to 230 lb. in weight, and from 8½ in. to 14 in. in diameter.

The smaller size, the 8½ in. bomb, has steel walls $\frac{3}{16}$ in. thick; the larger sizes have walls $\frac{5}{8}$ in. thick. The effect of the explosion of this type, compared weight for weight with that of the naval type, is much greater as the walls are $\frac{5}{8}$ in. thick. In the larger sizes the cast iron casing has been replaced by a casing of oil-hardened steel. Consequently, the bomb now breaks up into knife-edged pieces with the line of fracture at 45° to the surface instead of as formerly into blunt-edged pieces with the line of fracture at 90° to the surface.

3. *From Aeroplanes.*

(*a*) Small high explosive bomb 10 lb. in weight, 4 in. diameter and 13¾ in. in height. This was used till November, 1916. It was pear shaped.

(*b*) A 12 kilogram bomb, weighing 26½ lb., 3½ in. in diameter and 29¼ in. in height. This bomb had a long cigar-shaped body fitted with a tail composed of three fins which caused the body to rotate as it fell. The walls of this bomb were approximately $\frac{5}{8}$ in. thick, and broke up into small sharp jagged fragments of the same thickness, the pieces being usually about 1 in. long and ½ in. in width. They mark the ground round the explosion crater in a series of small furrows, radiating about 5 ft. to 10 ft. from the point of impact. Explosive charge :—2·64 lb. of a mixture of 60 per cent. T.N.T. and 40 per cent. hexanitrodiphenylamine and forms 11 per cent. of the total weight of the bomb.

(*c*) A 50 kilogram bomb, weighing 110 lb., 7 in. in diameter and 5 ft. 7 in. in height. A long cigar-shaped body fitted with sharp steel point and three vaned spiral tail. Owing to the relatively large quantity of high explosive employed, its destructive power is only slightly less than that of the 110 lb. (the smallest) airship bomb. The explosive charge is a mixture of trinitrotoluene and hexanitrodiphenylamine. Explosive charge :—44 lb. of same mixture as above forming 37 per cent. of total weight of bomb.

(*d*) Adapted trench mortar shell. It weighs 210 lb., is 9¾ in. in diameter, and 4 ft. 6 in. in height. It is of the usual cylindrical shape with blunt nose. It is fitted with three vanes. The pieces are extremely thin in proportion to its weight and size, *i.e.*, about $\frac{3}{16}$ in. They are made of shell steel and break up into the usual knife-edged fragments.

(*e*) A 100 kilogram bomb, weighing 220 lb., and replacing the above. Diameter 10 in. and height 6 ft. Similar in shape to the 50 kilogram bomb. Explosive charge :—116·6 lb. of the same mixture being 58 per cent. of the total weight of the bomb.

(*f*) A 300 kilogram bomb, weighing 660 lbs. Diameter 14·125 in. and height 9 ft. 2¼ in. Similar in shape to the above. Explosive charge 396 lb. of the same mixture, being 60 per cent. of the total weight of the bomb.

The walls of the steel nose portion of the bomb break up into large heavy

knife-edged pieces with very jagged edges, and the line of fracture at 45° to the surface. These pieces vary considerably in size; some may be found from 10 lb. to 12 lb. in weight and from 1 in. to 2 in. thick.

4. *Approximate radii of danger areas.*

(1) Pear-shaped H.E. bombs from naval airships :—
600 yds. in the open;
200 yds. in a pit 8 ft. deep and 3 ft. wide.
(2) Spherical H.E. bombs from military airships :—
1,000 yds. in the open;
300 yds. in a pit.
(3) H.E. bombs from aeroplanes :—
100 yds. in the open;
10 yds. in a pit.

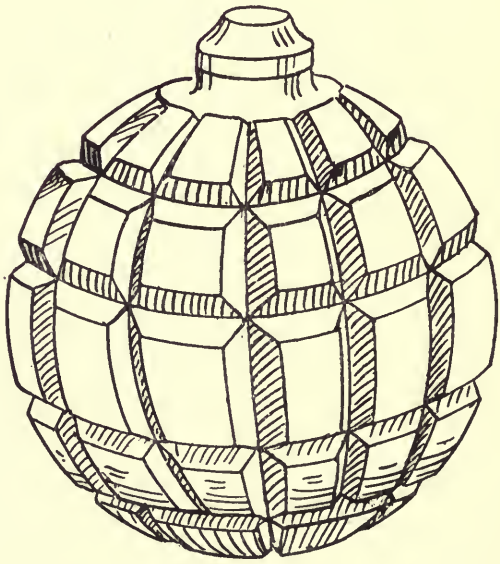
APPENDIX D.

Grenades used by the Germans.

1. *Cylindrical hand grenade* with handle and time fuze. (*Stielhandgranate* BZ) (Fig. 6).—Tin cylinder, 4 in. by 2⅞ in. in diameter. Charge of 10½ oz. Weight, 1 lb. 13 oz.

2. *Cylindrical hand grenade*, with handle percussion (*Stiel* or "Wilhelm's" *Handgranate* A2).—Similar in shape to above ("jam pot and stick"), but diameter of cylinder is 1 in. greater. Charge, 15·8 oz. of explosive. (Fig. 7.)

FIG 1. GERMAN SPHERICAL HAND GRENADE.



Scale ⅔

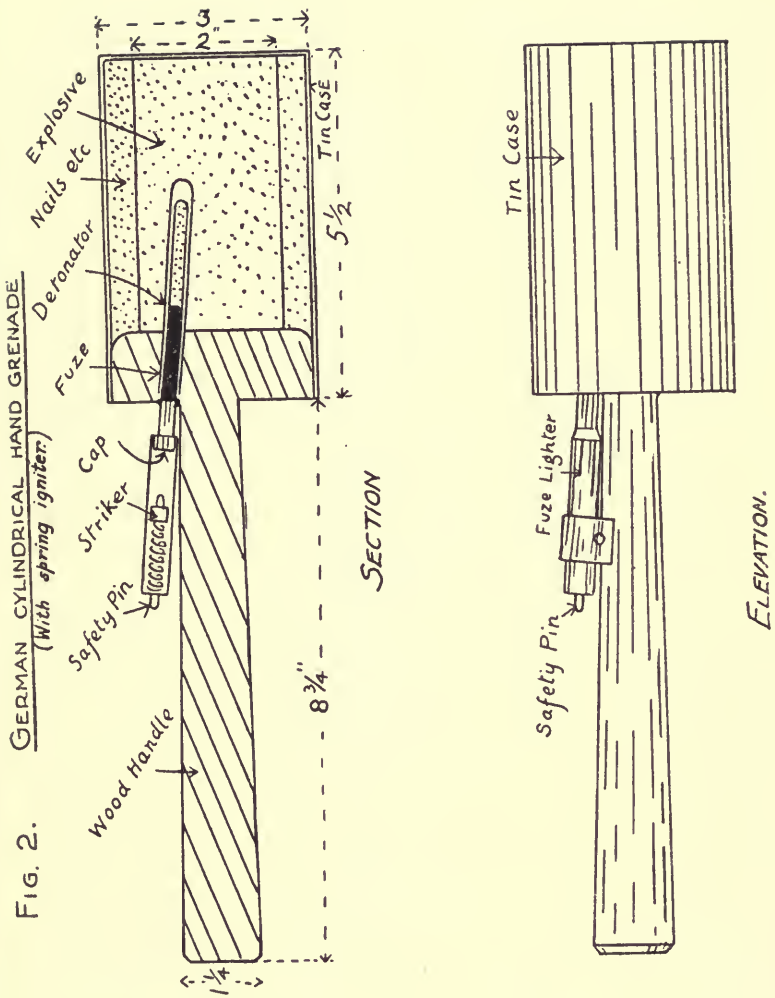
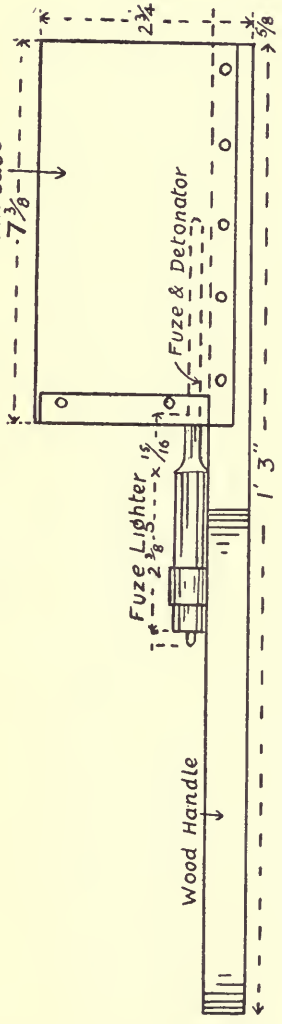


FIG. 2. GERMAN CYLINDRICAL HAND GRENADE (With spring igniter.)



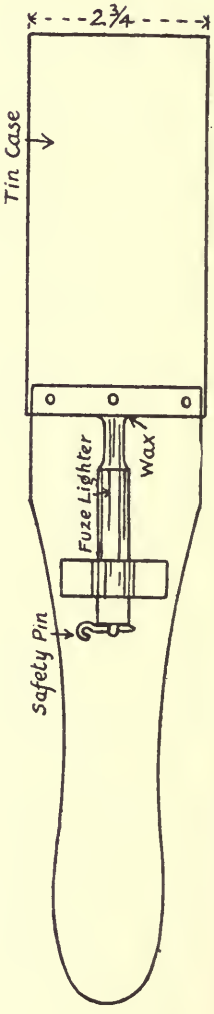
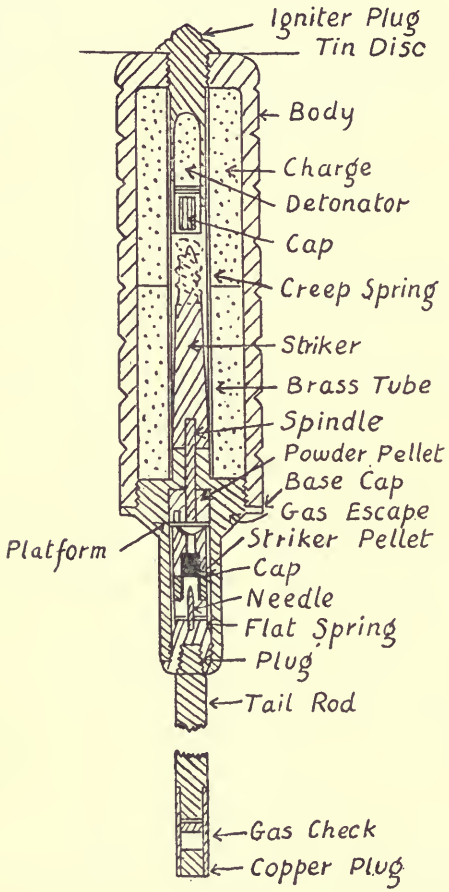


FIG. 3. GERMAN HAIR BRUSH HAND GRENADE.

3. *Egg hand grenade* (*Eierhandgranate*) (Fig. 8).—Weight, 11 oz. Can be thrown 50 yards. Cast iron, about 2 in. to 3 in. long by 1·77 in. in diameter. Filled with a special powder which does not require a detonator.

4. *Rifle grenade* 1914, percussion (*Gewehrgranate*)—Weight 2 lb. Maximum range, 380 yards. Cast iron, 0·2 in. thick and serrated to give fragments of sufficient size on detonation. Charge 2¾ oz.

FIG. 4. GERMAN RIFLE GRENADE 1913.



5. *Rifle grenade*, 1913, percussion (Fig. 4.)—Weight, 2 lb. Maximum range, 350 yards. Steel body 4·3 in. long and 0·16 in. thick, serrated longitudinally and transversely. Charge, 3·2 oz.

6. *Disc hand grenade*, percussion (*Diskushandgranate* 1915).—Two patterns, one weighing 15 oz., and made of sheet metal; one 13¼ oz. and made of cast iron. Consists of two iron shells, convex on outside, containing two circular bags of explosive each containing 2 oz. (Fig. 5.)

7. *Spherical hand grenade* (Fig. 1).—Weight, 1 lb. 10 oz. Can be thrown 30 yards. Body spherical, about 3 in. in diameter made of cast iron ⅛ in. thick. Filled with black powder or other explosive not requiring a detonator.

FIG. 5. DISC HAND GRENADE.

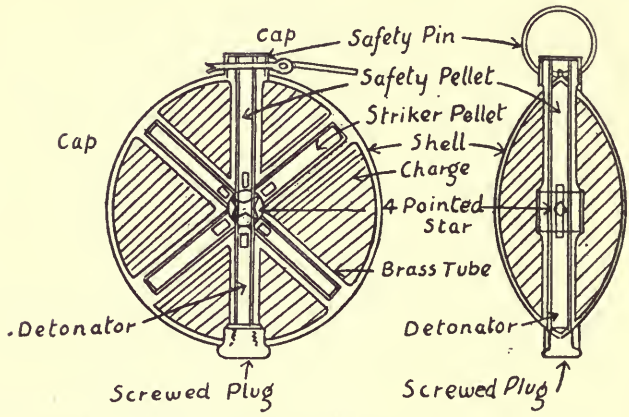
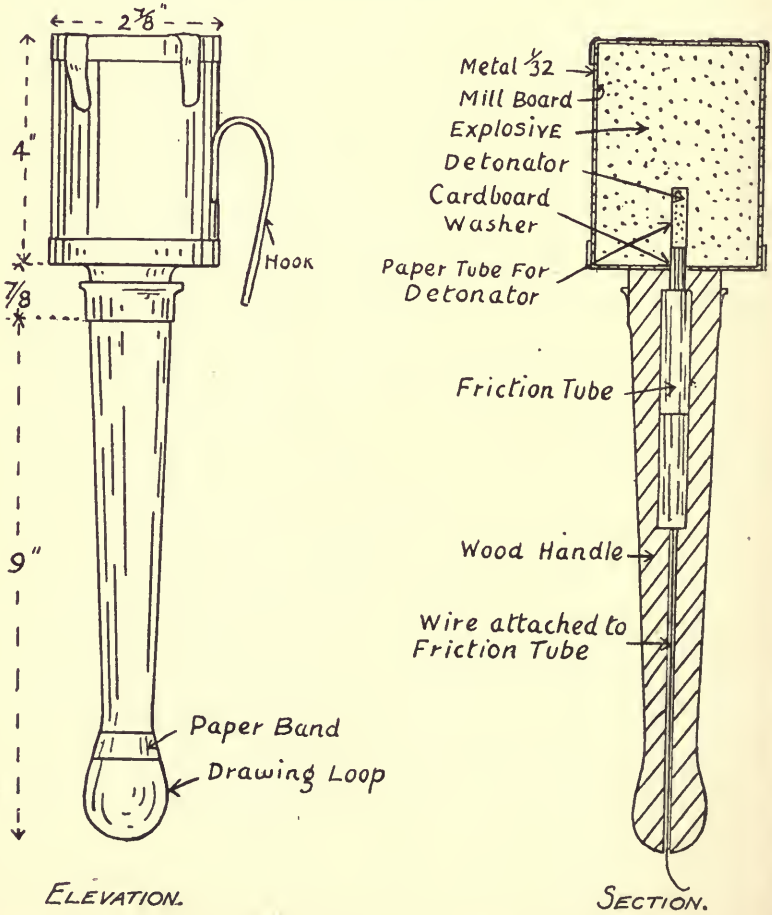


FIG. 6. GERMAN CYLINDRICAL HAND GRENADE.
*With handle (Earlier type).



8. *Parachute grenade.*—Percussion. Body consists of a tin cylinder of explosive with hemispherical head of larger diameter containing shrapnel bullets.

9. *Small tin hand grenade.*—Weight, 12 oz. Body a tin case $4\frac{7}{8}$ in. by $1\frac{11}{16}$ in. by $1\frac{11}{16}$ in. filled with explosive.

10. *Cylindrical hand grenade,* with spring igniter, charged with missiles, &c. Weight, $2\frac{1}{2}$ lb. Cylindrical tin of explosive 2 in. in diameter placed in a tin 3 in. in diameter, the space between being filled with nails, scrap iron, &c. (Fig. 2.)

11. *Hairbrush hand grenade,* with spring igniter (Fig. 3). Weight, $2\frac{1}{2}$ lb. Body a tin box $2\frac{3}{4}$ in. by $2\frac{3}{4}$ in. by 6 in., filled with explosive.

FIG. 7. GERMAN CYLINDRICAL HAND GRENADE. *With handle.*

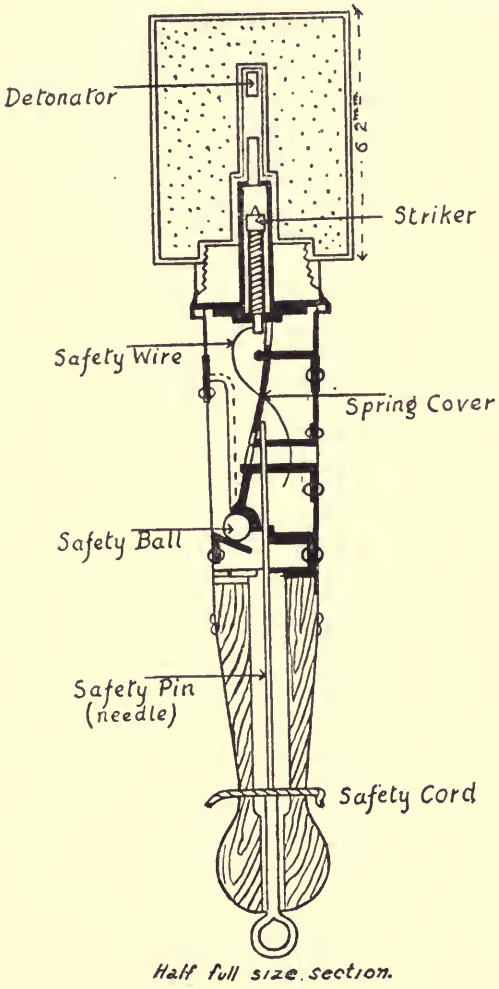
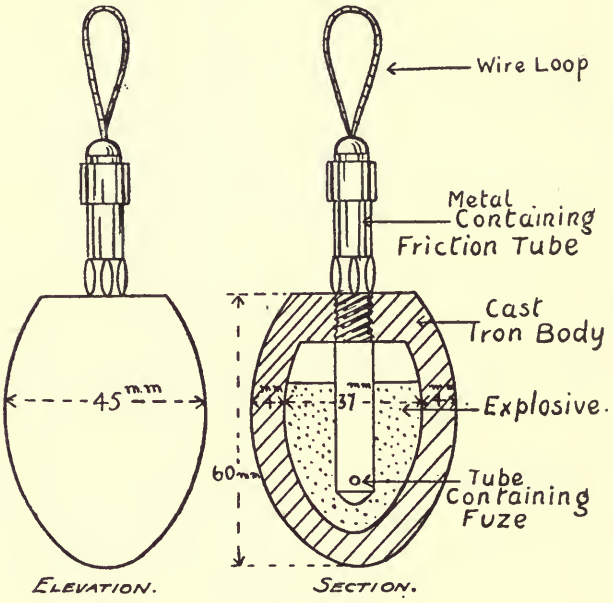


FIG. 8. GERMAN EGG HAND GRENADE.



APPENDIX E.

Bowlby Outfit for a Field Ambulance.

Additional Medical and Surgical Equipment for a Field Ambulance, a Cavalry Field Ambulance, or a Mounted Brigade Field Ambulance.

Article.	Field Ambulance.	Cavalry Field Ambulance or Mounted Brigade Field Ambulance.
Ether, ·720	lb. 3	2
Catgut, iodized, assorted sizes	tubes 60	40
Gloves, I.R., operation, sizes 7, 7½, & 8 ..	pairs 24	16
Needles, straight, triangular, various sizes	72	48
Needles, curved, Hagedorn's, various sizes	72	48
Needles, intestinal, curved and straight, various sizes	72	48
Silk, Chinese, twisted, assorted sizes ..	reels 24	16
Thread for ligatures, No. 60, 1 oz. reels ..	,, 12	8
Thread for ligatures, No. 90, 1 oz. reels ..	,, 12	8
Clippers, hair, size 00	2	1
Forceps, tongue, Guy's	1	1
Gag, mouth, Mason's	1	1
Inhalers, Schimmelbusch's	2	2
Instruments, eye, small (for excision) ..	case 1	1
Scissors, dressing, straight	pairs 4	3
Tubes, tracheotomy, large size	3	2

*Bowlby Outfit for a Casualty Clearing Station.**

Additional Medical and Surgical Equipment for a Casualty Clearing Station. Issued January 1918.

Acid picric, crystals, in 1 oz. bottles	bottles	20
Ether, ·720	lbs.	6
Iodine powder in tubes (standard pattern for 1% Aqueous solution)	tubes	200
Stovaine ampoules		36
Cushions air, round		12
Apparatus, saline, thermos, Souttar's		3
Bowls, E.I. in nests of 6, 4 of each size 6″, 8″, 10″, 12″, 14″, 16″		24
Catgut, iodized, assorted sizes	tubes	360
,, raw, sizes 1—3	hanks	6
Clippers, hair, size 00		2
Gloves, I.R., operation, sizes, 7, 7½, 8 (24 pairs each)	pairs	72
Irrigator, Cripp's 1 gallon, complete		1
Jugs, E.I., graduated, quart		6
Needles, abdominal, Sim's straight 4″		12
,, Bonnoy's ½-curved, sizes 9, 11 & 13		36
,, straight, triangular, various sizes		144
,, curved, Hagedorn's ,, ,, ...		144
,, intestinal, curved and straight, various sizes ..		144
Nozzles, Irrigator, Glass		12

* Exclusive of splints.

Plaster, rubber, adhesive, 2″	spools	36
Silk, Chinese, twisted, assorted	reels	144
Splints, rectangular, back-leg, wood, with foot-piece		20
Syringes, glass, 2 oz.		24
Thread for ligatures No. 60, 1 oz. reels	reels	36
,, ,, ,, ,, 90, 1 oz. reels	reels	36
Tubes, Paul's, small and medium		2
,, stomach, I.R., medium, size 18		2
Tubing, rubber, drainage, non-perforated (sizes 24, 25, 26, 27, 28)	yds.	50
Tubing, drainage, $\frac{3}{8}$″ diameter (size 21)	yds.	100
Bags, Lane's, 6 pint size, for subcutaneous infusion with double effluent and 14 needles		2
Boiler, water, copper, 5 gallons, on stand		3
Clamps, intestinal, Doyen's, with stout blades (A. & H. 5167)		2
,, ,, ,, ,, thin blades (A. & H. 5048)		2
Clips, towel, Backhaus'		24
Chisels, bone, flat		1
× Drill, hand, Doyen's, with skull perforator and burrs (2 sizes)	Set	1
Elevator, periosteal, Durham's		1
Forceps, artery, ordinary sizes		12
,, ,, Mayo-Ochsner's 8″		6
,, bullet		1
,, bone, parrot-bill, strong (Down 624)		1
,, dissecting, 5–inch		6
,, ,, toothed (2 in 3) 7″		1
,, ,, rat-tooth, 5″		1
,, sinus		1
,, skull Hoffman's, large		1
,, ,, de Vilbis'		1
× ,, ,, Montanavesi's (Cushing's modification)		2
,, sponge, 3 each 7″ & 9½″ (Down 1579)		6
,, sterilizer, Cheatle's (A. & H. 12526)		1
,, tissue Lane's 8″		12
,, tongue, Guy's		2
Gags, mouth, Mason's		1
Gouges, bone, medium, flat steel, ¼″, $\frac{5}{16}$″ and $\frac{7}{16}$″ (Down 463)		4
Holder, needle, Stanmore Bishop's or McPhail's		1
Inhaler, ether, open method, Rendle's or Silk's		1
Inhalers, Schimmelbusch's		3
Instruments, eye, small (for excision)	Case	1
Mallet, surgical, metal		1
Mirror, with forehead band		1
*Raspatory, rib, Doyen's		1
Retractor, Langenbeck's, hip joint 1¼″ × ½″		1
* ,, abdominal, Gossett's		1
,, Morris's in 3 sizes 1½″, 2″ and 2½″		3
Saw, amputation		1
Scalpels (in metal cases of 6 or 12), assorted		36
Scissors, dressing (9 straight, 3 curved)		12
Specula, ear, Toynbee's, set of 3	Set	1
× Sphygmomanometer, Tycos		1
Sterilizer, Schimmelbusch's, ordinary pattern		2
Stoves, Primus, for water boiler		3
Syringe, anæsthesia, Barker's spinal, Record pattern 2 c.c.		1
Tubes, tracheotomy, large sizes		3
Autoclave, Chamberland's No. 4, 34 cm., with paraffin stove		1

* Added—March 1918. × Added September 1918.

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